TP 8017E

# PEMBERTON MLS/STOL FLIGHT DEMONSTRATION PROJECT

## TECHNICAL REPORT

PREPARED FOR

TRANSPORTATION DEVELOPMENT
CENTRE
POLICY AND COORDINATION GROUP
TRANSPORT CANADA

BY

**McNEAL & ASSOCIATES
CONSULTANTS LTD.**

SUBCONTRACTORS TO

AirBC
Liaison Air Canada Connector

DECEMBER, 1988

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# FLIGHT
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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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AirBC conducted a series of flight tests aimed at establishing the technical feasibility of operated a scheduled air service into Pemberton, British Columbia, using a DeHavilland Dash 7 Short Take-off and Landing (STOL) aircraft in combination with a Micronav Microwave Landing System (MLS). The Pemberton approach winds through a tortuous valley line with 7000 foot mountains.

With special equipment installed in the aircraft, procedures acceptable to Transport Canada were developed and tested for approach, missed approach and departure flight paths. Difficulties in obtaining clean MLS signals on the missed approach required further tests involving both Micronav and Bendix, respectively suppliers of the ground and airborne systems. From these tests, recommendations were made to change the MLS back azimuth signals and the out of coverage antennas. Further tests were planned to verify these modifications.

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**16. Résumé**

La compagnie Air BC a lancé un projet d'essais en vol visant à vérifier la faisabilité technique d'une desserte régulière de l'aéroport de Pemberton en Colombie-Britannique, en utilisant des appareils à décollage et atterrissage courts (ADAC) de modèle deHavilland Dash-7 (DHC-7), guidés à l'approche et au décollage par système hyperfréquences (MLS). Pemberton est situé dans une étroite vallée entre des versants de 7000 pieds d'altitude.

L'appareil devant servir aux essais a été doté d'équipements spéciaux et des procédures de vol, conformes aux normes de Transports Canada, ont été définies puis évaluées pour les trajectoires d'approche, d'approche interrompue et de décollage.

Les problèmes de réception des signaux hyperfréquences recontrés lors des essais d'approche interrompue ont obligé à refaire une série d'essais, en collaboration avec les sociétés Bendix et Micronav, constructeurs des équipments MLS de bord et au sol, à la lumière desquels des mesures correctrices ont pu être recommandées, notamment par rapport à l'émission des signaux en azimut arrière et aux antennes d'invalidation des signaux hors champ. Des essais supplémentaires ont été prévus pour vérifier si les modifications proposées donnent les résultats escomptés.

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# EXECUTIVE SUMMARY

AirBC plans to operate a scheduled air service to Pemberton, B.C. to serve the Whistler resort area. The air service will be provided by deHavilland DHC-7 STOL aircraft capable of conducting steep approaches into the mountain valley airport.

A conventional instrument approach system could not be developed due to the surrounding mountain terrain affecting electronic signals of an Instrument Landing System (ILS) precision aid, or the obstacle clearance limits needed to safely operate in and out of the valley.

Combining Short Take-off and Landing (STOL) aircraft capabilities with microwave landing system (MLS) technology, however, allowed the design of an instrument approach system which could operate in a mountainous environment, and could provide the necessary track and elevation guidance needed to safely guide STOL aircraft into and out of the valley.

A comprehensive research program was conducted by AirBC, under the sponsorship of the Transportation Development Centre, to determine the feasibility of using MLS/STOL technology in order to provide a scheduled air service into the Pemberton Airport.

The research program had two principal objectives; to conduct the necessary flight tests and associated research to determine the application of MLS/STOL technology, and to meet Transport Canada's criteria for certification of AirBC air service into Pemberton.

AirBC, as the prime contractor, coordinated the MLS/STOL Flight Demonstration Project. Not only did the airline provide the aircraft, flight crews, and research test equipment, it also brought together the expertise necessary. This included Bendix-King, manufacturers of MLS airborne receivers, Micronav Ltd., manufacturers of the MLS ground system at Pemberton, deHavilland Division of Boeing Canada, manufacturers of the DHC-7 STOL aircraft, and the various branches of Transport Canada concerned with MLS technology and the certification process. An Advisory Review Committee was established to provide overall guidance on the flight demonstration project and MLS certification. The Committee was chaired by the Transportation Development Centre, and its membership included all interested groups. Liaison was maintained to ensure coordination of work tasks between responsible groups on the committee. Project administration was handled by AirBC. A Project Coordinator was sub-contracted for overall coordination, flight demonstration program, data

collection and analysis, reports, budgets, and liaison.

The research work plan was organized using a milestone type of format, due to the complexity of the project, and the uncertainties of obtaining various certification approvals. The milestone format provided the flexibility to adjust the work tasks and the project schedule to adapt to changing requirements of the project. Four basic milestones were established. At the completion of each milestone a progress report was presented to the Advisory Review Committee and the Transportation Development Centre. The milestones included:

Milestone 1: - Demonstration Set-up

- Engineer and install airborne equipment.
- Develop flight profiles.
- Develop detailed description of the technical aspects of the testing, including failure modes, cockpit procedures, data collection, Transport Canada documentation.
- Develop flight procedures evaluation.
- Monitor ground equipment installation and readiness.

Milestone 2: - Flight Testing

- Undertake initial flight tests to assess complete flight profile (approach, missed approach/departure).
- Undertake main flight test program.

Milestone 3: - Flight Procedures

- Complete flight procedures and file with Transport Canada.
- Establish ground school course.
- Evaluate training program.

Milestone 4: - Data Collection and Analysis

- Undertake data collection related to onboard performance of MLS received signal and position in space of aircraft throughout test program.
- Analyze data, evaluate results, and develop output information.
- Complete data collection analysis and evaluation and submit to Transport Canada.

Modifications were made to the work plan as the project was conducted. Most of the modifications were a result of schedule delays in the flight demonstration program.

The research test equipment included an AirBC deHavilland DHC-7 (C-GXPO) with STOL capabilities. The aircraft is equipped with a Sperry SPZ-700 Automatic Flight Control System, which integrates autopilot/flight director/air data systems. The guidance information from the flight director is interfaced with the MLS receiver, and includes an Integrated Attitude Director Indicator, and a Horizontal Situation Indicator. The DHC-7 is equipped with a weather radar system which can be used for ground mapping. It also is equipped with a Flight Data Recorder System. The Flight Data Acquisition Unit (FDAU) component of the system was expanded in the number of parameters to measure MLS related inputs for the tests. Dual Bendix-King MLS-21 airborne receivers were installed on the aircraft, including dual fore and aft antennae, MLS control head, and a special panel annunciator.

For the flight demonstration tests, an Advanced Navigation Inc. ANI 7000 Loran C receiver was installed in the DHC-7 to provide an independent navigation system, as a cross check on the MLS system's accuracy. Video cameras were installed on the aircraft to record flight instrument readings during the tests, as was an oscilloscope to view MLS signal output.

The Pemberton flight profile was originally developed in 1983 by deHavilland. The concept design was modified as a result of changes to ground equipment siting, obstacle clearance limitations, and standard AirBC flight procedures. An approach plate was developed by AirBC, as well as cockpit procedures and aircraft flight supplement, as part of the MLS/STOL Flight Demonstration Project.

The flight test program conducted nearly 80 hours of flight tests. About 15 flight hours' time was attributable to the initial flight program, which confirmed MLS signal reception and developed a flight profile and procedures to be followed in subsequent testing. The main test program was conducted between April and July of 1987, in which some 45 flight hours were accumulated. The main test program concluded with an initial series of flight checks conducted by Transport Canada towards certification. Due to MLS signal reception problems in the back azimuth coverage area, an additional 15 flight hours of testing was conducted in an attempt to resolve back azimuth reception problems which resulted in instrument "flagging".

The flight evaluation tests revealed no significant problems with the Pemberton MLS/STOL instrument approach. The DHC-7 aircraft handled the steep approach under all normal, abnormal, and emergency conditions. Tests were accomplished using 0°, 15°, 25°, and 45° flap, with no difficulty, but 25° flap is recommended as an approach standard. Approaches of 2° above and below the 7.7° design glidepath were accomplished with no unusual aircraft characteristics. Maneuverability of the aircraft to recapture the MLS signal from unusual positions was easily executed. One engine out conditions were handled well by the aircraft, including the critical climb gradient performance needed on the missed approach segment of the flight path. The slow approach speed of the DHC-7 in the landing configuration, and the excellent forward visibility provided confidence in performing close-in circling maneuvers in the narrow Pemberton Valley. MLS signal coverage and reception in the front azimuth area was excellent. The back azimuth reception, however, did experience problems, which resulted in momentary flagging (i.e. loss of signal) in the back azimuth coverage area.

Prior to a final flight check by Transport Canada to obtain certification, the following work tasks will have to be addressed:

- Back Azimuth Reception Tests - further flight tests are needed to ensure that steps taken to solve the back azimuth flagging problem have been resolved. It is estimated that 15 flight hours will be required.

- Ground Equipment Certification - Micronav Ltd. plans to have their MLS ground equipment type-certified by March 31, 1989. Upon completion of type certification, the Pemberton MLS installation can be certified by Transport Canada. Completion of some of the system components are required, as well as up-dated software and other modifications, as a result of type certification. Transport Canada's DHC-8, which is equipped with MLS test equipment, will be needed for certification of the ground facilities.

- Transport Canada Flight Checks - Deficiencies noted in the initial flight check by Transport Canada will have to be corrected. The final flight check will take place when the work tasks outlined are completed. About 10 flight hours will be required to complete the airworthiness flight tests.

The research program concluded that the Pemberton MLS/STOL Flight Demonstration Project met its first objective of determining the feasibility of the DHC-7 aircraft using an MLS instrument approach in the Pemberton Valley. The second research objective of obtaining Transport Canada certification was not met. While significant progress was made towards certification, it was not obtained.

There are still some work tasks to be completed, principally solving the back azimuth flagging problem. Certification, however, is an achievable goal.

In order to achieve this objective, two principal recommendations are made:

1. Conduct further flight testing to solve the back azimuth flagging problem, and to meet the requirements for a final Transport Canada certification flight check.
2. On-going coordination is still needed. The expertise of the Advisory Review Committee is required to ensure that the objective of certification is achieved. With final certification, Canada will have an MLS/STOL technology which can be demonstrated to other countries which require instrument approaches in mountain valleys to improve air service.

# SOMMAIRE

La compagnie AirBC envisage d'exploiter un service régulier à destination et en partance de l'aéroport de Pemberton en Colombie-Britannique, pour desservir le centre de villégiature de Whistler. Les vols seraient assurés par des avions à atterrissage et décollage courts (ADAC) de modèle deHavilland DHC-7, un appareil particulièrement approprié en terrain montagneux.

Il s'est avéré impossible d'adopter un système classique d'atterrissage aux instruments à cause du relief du terrain qui, d'une part, perturbe la transmission des signaux émis par les aides électroniques de précision et, d'autre part, ne permet pas de respecter la hauteur limite de franchissement d'obstacles autorisée par la procédure d'approche.

Toutefois, en composant avec les caractéristiques d'évolution des ADAC et la technologie des systèmes d'atterrissage hyperfréquences (MLS), on a pu mettre au point un système d'approche aux instruments tout à fait apte au guidage vertical et horizontal de ce type d'appareils dans un espace aérien aussi exigu que celui de la vallée de Pemberton.

Appuyée par le Centre de développement des transports (CDT), AirBC a lancé un vaste programme de recherche et d'expérimentation visant à vérifier la faisabilité technique d'un système d'atterrissage hyperfréquences qui autoriserait la mise en place d'un service ADAC en tous temps à l'aéroport de Pemberton.

Ce programme visait deux grands objectifs: d'abord, effectuer les recherches et les essais en vol nécessaires pour mettre au point et vérifier le système proposé; ensuite, satisfaire aux exigences de Transports Canada pour obtenir l'autorisation de procéder à des vols réguliers.

A titre de maître d'oeuvre, AirBC a assuré la coordination globale du project; non seulement elle a fourni les avions, les équipages, et le matériel de recherche et d'essai, mais AirBC a également réuni les compétences voulues, c'est-à-dire des représentants de: Bendix-King, constructeurs des récepteurs MLS de bord utilisés; Micronav Ltd., constructeurs des équipements MLS au sol; deHavilland, filiale de Boeing Canada et constructeurs des ADAC DHC-7; ainsi que des représentants des divers services de Transports Canada intéressés par la technologie MLS et responsables de la procédure de certification. Un comité consultatif d'orientation, formé de représentants de toutes les parties intéressées et présidé par le CDT, a été chargé de la coordination générale du projet et

des démarches en vue de la certification du système proposé. Une liaison constante a été maintenue entre les divers groupes, parties au dossier, afin d'assurer la coordination des travaux. La gestion du project a été assurée par AirBC. Enfin, la coordination des travaux a été confiée à un sous-traitant chargé plus précisément de coordonner les essais en vol, l'enregistrement et l'analyse des données, la préparation des rapports, l'affectation des crédits et la liaison.

Vu la complexité du projet et les incertitudes entourant l'obtention des certifications recherchées, il a été décidé de procéder par étapes. Cette façon de faire assurerait la souplesse nécessaire dans les cas où les circonstances obligeraient à modifier le plan de travail ou le calendrier d'exécution. Quatre grandes étapes ont été définies, aux termes desquelles un rapport sur l'état d'avancement des travaux a été présenté au Comité consultatif d'orientation et au CDT. Voici les quatre étapes et les travaux correspondants.

1re étape: préparation aux essais en vol

- Mettre au point et installer les équipements MLS de bord.
- Établir les profils de vol.
- Prévoir tous les détails techniques des essais, notamment en ce qui a trait au mode de fonctionnement en cas de pannes, aux procédures poste de pilotage, à l'enregistrement des données, aux documents à présenter au ministère des Transports.
- Établir une grille d'évaluation des procédures de vol.
- Contrôler d'installation et le réglage des équipements MLS au sol.

2e étape: essais en vol

- Faire les essais préliminaires en vol en vue de tracer un profil de vol complet (approche, approche interrompue, décollage).
- Entreprendre le programme principal d'essais en vol.

3e étape: procédures de vol

- Définir les procédures de vol et les soumettre à Transports Canada.
- Préparer un cours de formation au sol.
- Évaluer le programme de formation.

4$^e$ étape: enregistrement et analyse des données

- Enregistrer les données relatives à la réception et au traitement des signaux du système MLS et à la position correspondante de l'avion dans l'espace tout au long des essais.
- Analyser les données, évaluer les résultats et rédiger les rapports d'analyse.
- Compléter la collecte, l'analyse et l'évaluation des données et présenter les résultats à Transports Canada.

Des modifications ont dû être apportées au plan de travail à plusieurs reprises en cours de route, la plupart du temps à cause de retards dans le programme d'essais en vol.

L'appareil d'essai était un ADAC deHavilland DHC-7 (C-GXPO), doté d'un système de commande de vol automatique de modèle Sperry SPZ-700, comportant un pilote automatique, un directeur de vol et une centrale aérodynamique. Le directeur de vol qui comporte un indicateur directeir d'assiette intégré ainsi qu'un indicateur de situation horizontale, a été relié au récepteur MLS. Le DHC-7 est doté en outre d'un radar météorologique permettant la représentation sol, ainsi que d'un enregistreur de vol. La capacité du bloc d'acquisition de données (FDAU) a été augmentée pour pouvoir enregistrer les paramètres du système MLS. L'appareil a été équipé de deux récepteurs Bendix-King MLS-21 avec antennes doublées à l'avant et à l'arrière de l'appareil, d'un boîtier de commande MLS et d'un avertisseur spécial placé au tableau.

Pour la durée des essais, l'avion a été équipé d'un récepteur Loran-C de modèle ANI 7000 construit par Advanced Navigation Inc., destiné à contrôler la précision du système MLS. Des appareils de télévision en circuit fermé ont été placés à bord de l'appareil pour enregistrer les indications des instruments de vol, ainsi qu'un oscilloscope qui permettrait d'observer l'évolution des signaux du MLS.

Le profil de vol à l'aéroport de Pemberton avait été établi par la compagnie deHavilland en 1983. Il a été modifié pour tenir compte du déplacement de certains équipements au sol, du changement de la hauteur limite de franchissement d'obstacles et des procédures normales de vol de la compagnie AirBC. Celle-ci a aussi élaboré une feuille de percée ainsi que des procédures poste de pilotage et des procédures supplémentaires de vol pour les besoins du présent projet.

Les essais en vol ont duré à peu près 80 heures, dont 15 environ ont été consacrées aux essais préliminaires, destinés à vérifier la réception des signaux MLS, à tracer un profil de vol et à définir les procédures de vol en vue des essais subséquents. Le programme principal d'essais en vol s'est déroulé du mois d'avril au mois de juillet 1987 et a duré environ 45 heures. Il s'est terminé par une première série de vérifications en vol effectuées par Transports Canada en vue de la certification. A cause de problèmes de réception des signaux d'azimut arrière, signalés par l'absence d'indication des instruments, 15 heures supplémentaires d'essais en vol ont dû être ajoutées.

Les essais en vol n'ont révélé aucun problème important quant au guidage par système MLS d'appareils ADAC à l'aéroport de Pemberton. Le DHC-7 a réussi l'approche dans toutes les conditions: normales, anormales et d'urgence. Les essais ont été effectués sans problème avec les volets braqués à 0°, 15°, 25° et 45°. Toutefois, un angle de braquage de 25° est recommandé comme procédure normale. L'approche a également été essayée sans problème à 2° de plus et de moins que l'angle de descente prévu (7,7°). Les manoeuvres nécessaires pour remettre l'appareil dans le faisceau des signaux du MLS à partir de positions inhabituelles ont été facilement réussies. L'appareil s'est bien comporté lorsqu'un des réacteurs a été mis hors service et ce, même à la remontée en pente critique lors de l'essai d'approche interrompue. La faible vitesse d'approche en configuration d'atterrissage du DHC-7 et l'excellente visibilité qu'il autorise ont permis de manoeuvrer en toute confiance dans d'espace restreint de la vallée de Pemberton. La couverture aximutale et la réception dans le secteur azimut avant se sont avérées excellentes. Par contre, la réception dans le secteur azimut arrière a posé quelques problèmes qui se sont traduits par une absence temporaire d'indication des instruments.

Avant que le ministère des Transports puisse procèder à la dernière vérification en vue de la certification, il faudra voir aux points suivants:

- Vérification de la réception en azimut arrière. Il faudra faire d'autres essais en vol pour vérifier si les modifications apportées au système ont bien corrigé le problème de réception en azimut arrière; il faut prévoir à cette seule fin environ 15 autres heures de vol.

- Certification de l'équipement au sol. La compagnie Micronav Ltd. prévoit obtenir l'homologation de type pour ses équipements MLS au sol avant la fin de mars 1989. Le système MLS de l'aéroport de Pemberton pourra alors être certifié par Transports Canada. L'homologation de type obligera à mettre au point certains des composants du système, à mettre les logiciels à jour et à apporter certaines autres modifications. L'appareil DHC-8 de Transports Canada qui est équipé d'un système MLS d'essai devra être utilisé pour la certification des équipements au sol.

- Vérifications en vol par Transports Canada. Les problèmes soulignés par Transports Canada lors des premiers vols d'inspection devront être corrigés. La vérification finale aura lieu lorsque les travaux ci-dessus auront été effectués. Il faut prévoir environ 10 heures de vol pour les essais de navigabilité.

Le programme de recherche et d'expérimentation mené par AirBC a permis d'établir qu'un DHC-7 peur atterrir à l'aéroport de Pemberton, guidé par un système hyperfréquences. Par contre, le deuxième objectif, à savoir la certification du système proposé, n'a pas été atteint. On peut cependant penser que la certification sera accordée lorsque les problèmes soulignés par les inspecteurs, et en particulier le problème de réception des signaux d'azimut arrière, auront été corrigés.

Pour parvenir à la réalisation du deuxième objectif, il y aurait lieu de:

1. Procéder à d'autres essais pour corriger le problème de réception des signaux d'azimut arrière et satisfaire aux conditions imposées par Transports Canada pour passer à l'étape du dernier vol de certification.

2. Continuer d'assurer la coordination des travaux. Il est essentiel de pouvoir compter sur les ressources du Comité consultatif d'orientation pour parvenir à la certification recherchée. Le Canada serait alors doté d'une technologie MLS/ADAC qu'il pourrait exporter vers d'autres pays connaissant des besoins analogues à ceux de la vallée de Pemberton.

## PEMBERTON MLS/STOL FLIGHT DEMONSTRATION PROJECT
## TECHNICAL REPORT

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## GLOSSARY - ABBREVIATIONS

| | |
|---|---|
| AC | Alternating Current |
| Adabatic | Vertical temperature reduction which creates air movement currents. |
| ADF | Automatic Direction Finder |
| AEO | All Engines Operative |
| AES | Atmospheric Environment Service |
| AGL | Above Ground Level |
| A/P | Approach |
| ARINC | Aeronautical Radio Inc. (sets standards for avionics interface) |
| ASL | Above Sea Level |
| ATA | Air Transport Association |
| ATAP | Air Transport Assistance Program (Gov't of BC) |
| ATC | Air Traffic Control |
| ATE | Along Track Error |
| AUTO | Automatic |
| AWOP | All Weather Operations Panel (ICAO) |
| AZ | Azimuth Antenna |
| BAZ | Back Azimuth |
| C Band | Microwave Radio Frequency Range |
| C of G | Centre of Gravity |
| CAPT | Captain |
| CAS | Calibrated Air Speed |
| CAT 1 | Category 1 Precision Approach (200' DH - 1800 RVR) |
| CAT II | Category 2 Precision Approach (100' DH - radio altimeter required/special avionics training - 1200 RVR) |
| CAT III | Category 3 Precision Approach - No decision height - 0, 150, 700 RVR, depending on support equipment used. |
| CDI | Course Deviation Indicator |
| CDU | Control Display Unit |
| CEP | Circular Error Probability |
| CH | Channel |
| Class A | Transport Canada Navigation Facilities - private ownership/private use - usually no redundancy. |
| Class B | Transport Canada Navigation FAcilities - private ownership/public use - some redundancy (eg. power supply) |
| Class C | Transport Canada Navigation Facilities - public ownership/public use - complete redundancy. |
| CMN | Central Motion Noise |

| | |
|---|---|
| CTE | Cross Track Error |
| DAR | Design Approved Representative |
| dB | Decibel |
| DFDR | Digital Flight Data Recorder |
| DH | Decision Height |
| Dichroic | Crystal which exhibits two different readings when viewed from two different directions. |
| DME | Distance Measuring Equipment |
| DME/P | Precision Distance Measuring Equipment |
| DOT | Department of Transport |
| DPSK | Differential Phase Shift Keying |
| E field antenna | Blade type antenna |
| ECD | Envelope-to-Cycle differences |
| EFIS | Electronic Flight Information System |
| EL | Elevation |
| Eng. | Engine |
| FAA | Federal Aviation Adminstration |
| FAF | Final Approach Fix |
| FAP | Final Approach Point |
| FAR | Federal Aeronautical Regulations (FAA) |
| FD | Flight Director |
| FDAU | Flight Data Acquisition Unit |
| FM | Frequency Modulated |
| F/O | Flight Officer |
| FPM | Feet Per Minute |
| FTE | Flight Technical Error |
| GA | Go-Around |
| Gen | Generator |
| GHz | Giga Hertz |
| GPWS | Ground Proximity Warning System |
| GRI | Group Repetition Interval |
| GS | Glideslope |
| HSI | Horizontal Situation Indicator |
| Hz | Hertz |
| IAF | Initial Approach Fix |
| IAP | Initial Approach Point |
| IAS | Indicated Air Speed |
| IB | Inbound |
| ICAO | International Civil Aviation Organization |
| IF | Intermediate Frequency |
| IFR | Instrument Flight Rules |
| ILS | Instrument Landing System |

| | |
|---|---|
| IMC | Instrument Meteorological Conditions |
| INS | Inertial Navigation System |
| IRDP | Industrial & Regional Development Program |
| IRFIS | Inertial flight inspection system |
| ISA | International Standard Atmospheric Temperature |
| KHz | Kilo Hertz |
| kts. | Knots |
| KVa | Kilowatt Voltage Amperes |
| LH | Left Hand |
| LOC | Localizer |
| LOP | Line of Position |
| LSI | Large scale integration |
| MAN | Manual |
| MAP | Missed Approach Point |
| MCP | Maximum Climb Power |
| MDA | Minimum Descent Altitude |
| MEA | Minimum Enroute Altitude |
| MLS | Microwave Landing System |
| MMEL | Master Minimum Equipment List |
| MOCA | Minimum Obstruction Clearance Altitude |
| N field antenna | Omni directional in azimuth button antenna |
| NASA | National Aeronautics & Space Administration |
| NAV | Enroute Navigation |
| NDB | Non-Directional Beacons |
| NM | Nautical Miles |
| OAT | Outside Air Temperature |
| OCI | Out-of-Coverage Indicator |
| OCL | Obstacle Clearance Limits |
| OEI | One Engine Inoperative |
| OR | Operational Requirement |
| Parallax | Apparent displacement of an observed object due to the difference between two points of view. |
| PFLF | Power For Level Flight |
| Prop | Propeller |
| RAC | Responsibility/Authority/Communications Matrix |
| Radome | Dome shaped housing for radar antenna |
| RCU | Receiver Computer Unit |

| | |
|---|---|
| RF | Radio Frequency |
| RH | Right Hand |
| RNAV | Area Navigation |
| RPM | Revolutions per Minute |
| RVR | Runway Visual Range |
| SL | Sea Level |
| SLT | Select |
| SM | Statute Miles |
| SNR | Signal to Noise Ratio |
| SOP | Standard Operating Procedures |
| STC | Supplemental Type Certificate |
| STOL | Short Take-Off and Landing |
| Superheterodyne | Method of changing the frequency of an incoming radio signal. |
| TACAN | Tactical Air Navigation Aid (VHF Omni Range) |
| TAS | True Air Speed |
| TCH | Threshold Crossing Height |
| TD | Time Difference |
| TDC | Transportation Development Centre |
| TDM | Time Divison Multiplexed |
| TOA | Time of Arrival |
| TRSB | Time-reference scanning beam |
| TSO | Technical Service Order |
| TST | Test |
| Unisys | Sperry Corporation |
| V | Volts |
| V airway | VHF navigation aid airway |
| Vapp | Approach Speed |
| $V_{cl}$ | Climb speed |
| VCO | Voltage Controlled Oscillator |
| $V_{dc}$ | Voltage, direct current |
| $V_{enr}$ | Velocity enroute |
| $V_{fe}$ | Maximum speed for flap extension |
| VFR | Visual Flight Rules |
| VHF | Very High Frequency radio |
| VLD | Valid |
| $V_{lo}$ | Maximum speed for landing gear extension |
| $V_{mo}$ | Velocity for Maximum Operation |
| VOR | VHF Omni Directional Range Navigation Aid |
| VORTAC | Combined VOR-TACAN navigation aid |
| $V_{ref}$ | Velocity in ref. to weight & temperature charts |
| $V_s$ | Velocity (stall) |
| WAT | Weight and Temperature Performance Charts |

# 1. INTRODUCTION

This introductory chapter outlines the purpose of the technical report, presents the objectives of the research program and the scope of the program. The coordination role of AirBC is explained, and an outline of the various chapters is discussed.

## 1.1 Purpose of Technical Report

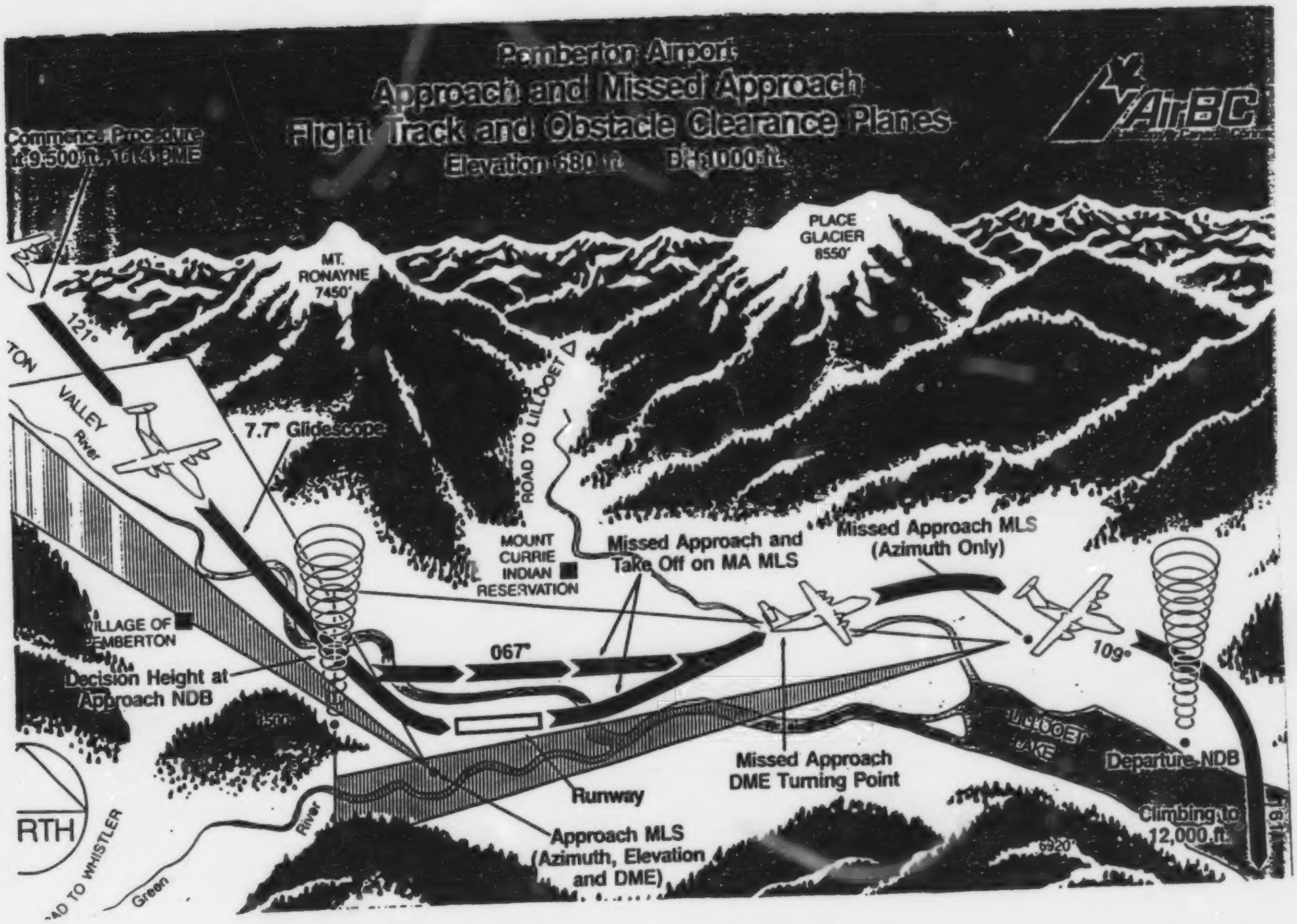
A comprehensive research program was coordinated by AirBC to determine the feasibility of using deHavilland (a Division of Boeing Canada) DHC-7 aircraft on a scheduled route service to and from Pemberton, B.C. A microwave landing system (MLS) has been designed and installed in the Pemberton valley, which provides the necessary track and elevation guidance for a mountain valley instrument approach/missed approach. An AirBC DHC-7 aircraft, which has short take off and landing (STOL) performance capabilities needed for steep approach/missed approach profiles, and which is equipped with MLS receivers was used to test the feasibility of using the MLS. The purpose of this Technical Report is to provide a synopsis of the research program which was undertaken, and to provide recommendations for further research tasks on developing MLS/STOL technology. Figure 1, overleaf, graphically illustrates the Pemberton MLS/STOL instrument approach.

## 1.2 Objectives

The objective of the technical research program was to conduct the necessary flight tests and associated research to determine the feasibility of the DHC-7 to meet Transport Canada criteria for the use of an MLS instrument approach/missed approach in the Pemberton Valley. Transport Canada certification of AirBC to use suitably equipped DHC-7 aircraft under instrument weather conditions at Pemberton is a second and ultimate objective of the research program.

The overall goal of the research contract between the Transportation Development Centre and AirBC, called for the development of expertise, techniques, and equipment, in cooperation with the air transportation industry, which would lead to the improvement of safety, efficiency, and productivity in the Canadian air transportation system.

Figure 1
Pemberton MLS/STOL Instrument Approach


Pemberton Airport
Approach and Missed Approach
Flight Track and Obstacle Clearance Planes
Elevation 680 ft. DH 1000 ft.
AirBC
Commence Procedure at 9,500 ft. 11.4 DME
MT. RONAYNE 7450'
PLACE GLACIER 8550'
121°
VALLEY
River
7.7° Glidescope
ROAD TO LILLOOET
MOUNT CURRIE INDIAN RESERVATION
Missed Approach and Take Off on MA MLS
Missed Approach MLS (Azimuth Only)
VILLAGE OF PEMBERTON
067°
109°
Decision Height at Approach NDB
Runway
Missed Approach DME Turning Point
LILLOOET LAKE
Departure NDB
Climbing to 12,000 ft.
6920'
Approach MLS (Azimuth, Elevation and DME)
RTH
ROAD TO WHISTLER
Green
River

The specific objective of the terms of reference was "to establish flight profiles, develop associated integrated flight procedures, and test and verify that the application of a special microwave landing system (MLS) arrangement can safely demonstrate Canadian MLS and STOL technologies under difficult operational conditions in mountainous terrain, requiring the steep curved approach possible only with the DHC-7 STOL aircraft.

## 1.3 Scope of Research

The scope of the research program undertaken by AirBC was outlined in the contract between the Transportation Development Centre and AirBC, dated March 9, 1987. The contract outlines the project research Milestones, and the work tasks to be conducted within each of the Milestones. The following presents the various Milestones:

| | |
|---|---|
| Milestone 1 | Demonstration Set-up. |
| Milestone 2 | Flight Testing. |
| Milestone 3 | Flight Procedures |
| Milestone 4 | Data Collection and Analysis |

The research project involved the operational demonstration of two major research initiatives:

a) technical investigation of MLS performance in mountainous terrain, and

b) development and demonstration of procedures for the approach, missed approach, and departure.

All flying operations were to be conducted under Visual Flight Rules (VFR) conditions, since the approach has not been approved for Instrument Flight Rules (IFR). Arrangements were made by AirBC to provide specialized equipment, as well as to provide and operate the DHC-7 test aircraft.

## 1.4 Role of AirBC

AirBC's role in the research program was to be the prime contractor. AirBC also had the role of coordinating with its sub-contractors and interested organizations, to ensure that all flight tests were conducted with the desired equipment and specialist expertise being on hand. Liaison with Transport Canada was to be maintained throughout the project by AirBC.

AirBC provided the deHavilland DHC-7 STOL aircraft and the necessary flight crews to operate the various flight tests. A DHC-7, C-GXPO, had been equipped with dual Bendix-King MLS 21 receivers, including wiring harness and dual fore and aft antennae. The aircraft was also equipped with instrumentation and recording devices to observe and collect data. AirBC avionics staff, assisted by Pacific Avionics Ltd., were responsible for installing the equipment.

AirBC retained a Project Coordinator under sub-contract, McNeal & Associates Consultants Ltd., of Vancouver, B.C., to oversee the research project and to coordinate all activities. Coordination was arranged with the following:

> Bendix-King, of Fort Lauderdale, Florida, provided assistance in installing the MLS receivers and providing expertise related to various aspects of MLS reception. Ongoing support was also provided by a Bendix-King technical representative, based in Portland, Oregon.

> Micronav Ltd., of Sydney, Nova Scotia, manufacturers and installers of the MLS ground equipment, provided technicians during the flight tests, as well as technical liaison with Bendix-King.

> deHavilland Division of Boeing Canada, Downsview Ontario, provided assistance in developing the approach chart and certification information on the DHC-7 aircraft.

> Advanced Navigation, Inc., of Frederick, Maryland, provided an ANI 7000 Loran C receiver during the tests, to cross check navigation accuracy during the flight tests.

> Transport Canada, Pacific Region, the MLS Project Office, and Airworthiness Branch in Ottawa, provided advice and suggestions with regard to equipment installed on the aircraft, flight testing procedures, and assistance with recording devices.

## 1.5 Outline of Technical Report Presentation

A brief outline of the contents of the technical report herein is presented:

### > Microwave Landing System Review

This chapter reviews the principles of MLS, pointing out the advantages and disadvantages of MLS. The chapter also discusses the available ground and airborne equipment, and presents the International Civil Aviation Organization (ICAO) installation schedule.

### > Need for Precision Approach at Pemberton

The nearby Whistler Resort's year round recreational attractions are expected to provide the demand for air travel to the Pemberton Airport. Air demand projections are reviewed in this chapter. The difficulties of instrument approaches in mountainous terrain and weather related issues are also discussed. The successful Vail, Colorado, MLS operation flown by DHC-7 aircraft is outlined as a role model, and the historical development of an MLS/STOL system for the Pemberton Valley is presented.

### > Advisory Review Committee

This chapter outlines the purpose of the committee and its members, who provided technical advice to the research project. It also notes the liaison needed to coordinate the various activities. The project administration framework is outlined, particularly between AirBC's Project Coordinator and the Transportation Development Centre. Public relations resulting from the research project are also noted in this chapter.

### > Certification Process

Transport Canada is responsible for the certification of an MLS air service. The certification process is explained in this chapter with regard to the ground and airborne equipment installations. The aircraft flight test requirements are also explained, as well as the airworthiness certification needed before final approval.

> **Research Work Plan**

The project research plan is detailed, noting the Milestone format to monitor the various work tasks to be completed. During the course of the research program, certain modifications were made to the work plan. These modifications are discussed, including changes to the research schedule.

> **Research Test Equipment**

The research test equipment is identified in this chapter, and the purpose of the equipment is explained. Test equipment is categorized into the aircraft, ground equipment, and airborne equipment.

> **Flight Profile Development**

This chapter outlines the steps taken to develop the flight profile for the Pemberton MLS approach. It includes a discussion of the DHC-7 flight characteristics, particularly with regard to steep approaches and one-engine out missed approach climb configurations. The chapter also outlines the development of the approach plate needed to guide pilots during the procedures, and the cockpit procedures to be followed by the flight crew. Development of an aircraft flight supplement to be included in the company flight manual, and flight crew qualifications regarding training for MLS operations are also noted in the chapter.

> **Flight Test Program**

The flight test program was divided into two phases. The initial flight tests were designed to test navigation receiver reception, to conduct the various flight profiles, and select the optimum flight profile. Various flight failure modes were simulated, and an initial evaluation was made to verify the procedures and to modify tests, if necessary, in the second phase.

The second phase of the tests collected data during the various tests, and made a preliminary analysis of the information collected. Problems experienced during the evaluation program were also noted.

An initial Transport Canada flight test was conducted during this second phase of the flight testing.

> Back Azimuth Reception

The flight test program revealed a back azimuth reception problem. This chapter provides a synopsis of the reception problem. It also reviews the additional flight tests which made an attempt to solve the problem. The results of these additional tests are noted, as well as the work tasks needed.

> Navigation System Risk Analysis

An independent risk analysis study was conducted, and the results of this study are reviewed and summarized in this chapter.

> Final Flight Check Program

This chapter outlines the final steps needed prior to final authorization by Transport Canada to operate a scheduled air service.

> Conclusions of Research

The conclusions reached during the MLS/STOL flight demonstration research program are summarized in this chapter. It reviews the major work tasks accomplished, and discusses whether or not the project objectives have been met.

> Recommendations

This final chapter recommends further testing needed before the final flight check, and the need for ongoing coordination to ensure that MLS and STOL technology achievements are met.

## 2. MICROWAVE LANDING SYSTEM REVIEW

A review of MLS is presented in this chapter in order to provide an overview of technical terms and features which are introduced in later chapters of the technical report. The review provides an understanding of MLS and its status as a precision approach navigation aid in terms of a world-wide implementation schedule.

### 2.1 Principles of MLS

Microwave Landing Systems were designed to provide precision guidance capable of satisfying a full range of operational requirements, both civil and military, for all types of weather conditions. It overcomes inherent limitations of the conventional Instrument Landing System (ILS) in that radiated signals are minimally affected by surrounding terrain, structures and weather. MLS will replace ILS over the next 15 years, as agreed to by the United Nations sponsored International Civil Aviation Organization (ICAO).

MLS provides accurate lateral, vertical, and distance guidance signals electronically through space to suitably equipped aircraft. Like ILS, it is considered a precision approach system because of the vertical guidance and the generally lower minima possible, due to the precision track and elevation information provided to the pilot.

An MLS comprises azimuth, elevation, and distance measuring functions, which provide continuous, accurate, three-dimensional position information with a wide signal coverage volume.

Signal transmissions are made in the 5 GHz microwave range. This high frequency range provides less disruption of signal than existing lower frequencies. The Time Reference Scanning Beam (TRSB) signal format is based on time-division multiplexing, wherein angle guidance information transmitted is broadcast in a timed sequence. The angle information is derived by measuring the time difference between the successive sweeps of highly directive, immodulated narrow fan beams. A preamble signal (eg. Basic Dataword software) precedes each scanning beam transmission, which identifies the next scan function to be transmitted (eg. approach azimuth, approach elevation, back azimuth angles). The preamble also synchronizes the airborne receiver signal processing circuits and logic to receive the transmitted signal. Range information is provided by distance measuring equipment (DME), normally co-located with the MLS azimuth station.

Currently, conventional DME are used, but provision for future precision DME/P with improved range accuracy (eg. +- 100 feet in the final approach mode) is incorporated into the MLS design.

The MLS azimuth is analogous to an ILS localizer, but has a much wider proportional guidance signal (eg. normally up to +40° to -40° from an extended centre line, and can be extended to +60° to -60°). The wider coverage allows a single azimuth to provide approach guidance to additional runways or helipads on the same airport.

The MLS elevation is analogous to the glideslope facility of the ILS, except that the elevation guidance allows for glidepath angles up to 15°, rather than the fixed 2.5°-3.0° used in ILS. The coverage of the elevation signal extends through the total airspace volume, as covered by the azimuth signal. This allows multiple flight paths to be selected, as well as curved and segmented approaches.

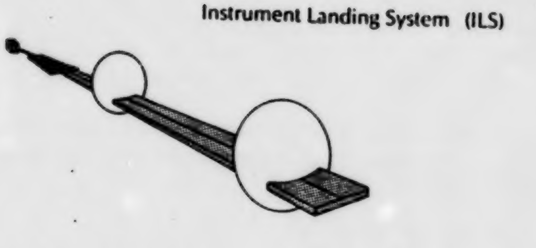
The MLS back azimuth, where installed, is identical to the azimuth, and is somewhat analogous to the back course of an ILS localizer. Its purpose is to provide guidance for departures and missed approaches where positive track information is required for obstacle clearance reasons.

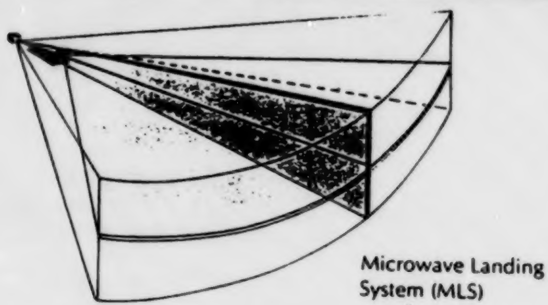
The airborne MLS receiver is a conventional superheterodyne receiver, providing up to 200 channels. The receiver decodes the ground data being transmitted to determine the function being received. The receiver digitizes the angle guidance signal, tracks the strongest, consistent TO and FRO signals, and interfaces the received information with the output controls and displays in the aircraft cockpit. The receiver processor also has signal acquisition track and validation features which ensure the angle guidance has a high degree of integrity in the presence of multipath and other forms of signal interference. The receiver also has the capability of decoding basic and auxiliary time-multiplexed data and interfacing with conventional aircraft displays, on-board computers, autopilots, and other devices.

Figure 2 illustrates the basic features of MLS signal transmission coverage, and compares MLS to conventional ILS.

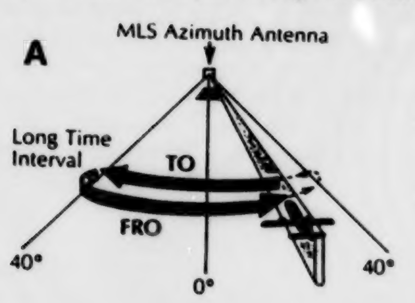
Figure 2
Features of MLS Signal Transmission

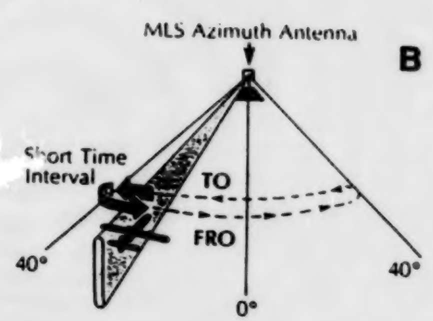
# How MLS works



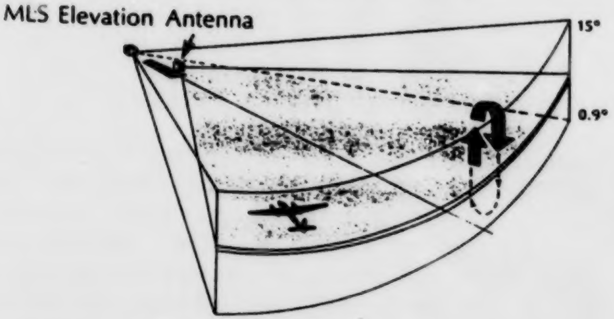


ILS provides a single, fixed approach path to the runway which all aircraft, regardless of flight characteristics, must follow. MLS uses two *scanning beams* — one lateral and one vertical — to provide a variety of approach paths for different aircraft types, from airline jets through STOL aircraft to helicopters.





The MLS *azimuth* beam sweeps rapidly and continuously to left and right of the extended runway centre line. Normally, the sweep will be to forty degrees either side of the centre line, but this can be adjusted to suit local terrain or other requirements. To determine its location, the aircraft receiver measures the time between "TO" and "FRO" sweeps of the beam. A long interval (A above) indicates the aircraft is to the right of the centre line, while a short interval (B above) indicates the aircraft is to the left.



The MLS *elevation* beam is a fan-shaped beam which sweeps rapidly up and down through the azimuth coverage area. The aircraft receiver measures the time between the sweeps of the elevation beam to determine the aircraft's descent angle.

After selecting the appropriate inbound azimuth and elevation approach angles on his aircraft MLS receiver, the pilot obtains precise fly right/fly left, fly up/fly down cross pointer guidance down the approach path. During his approach, the pilot also receives continuous distance-to-go information from a separate *precision distance measuring equipment* (PDME) transmitter, normally located at the MLS azimuth transmitter site.

Some MLS installations may include a *back azimuth* transmitter, located off the approach end of the runway, which sweeps a second azimuth scanning beam through the missed approach area to provide precise guidance during missed approach and departure procedures. Azimuth, elevation, and back azimuth stations transmit in continuous rapid sequence on the single MLS frequency channel assigned to the specific runway approach.

## 2.2 Advantages and Disadvantages of MLS

The U.S. Federal Aviation Administration (FAA) has conducted comprehensive benefit/cost studies of MLS in 1980, 1987, and in 1988. These studies quantified the benefits and costs of MLS into various categories.

### Advantages:

There are eight specific areas where MLS provides benefits over ILS which can be quantified. These are summarized from the Federal Aviation Administration (FAA) studies as follows:

### 1. Resolution of ILS Siting Constraints

Conventional ILS has both signal emission and instrument approach limitations at certain sites. It is estimated in the U.S. that 25% of the 773 ILS approaches at 531 airports do not achieve nominal Category 1 (CAT 1) ceiling and visibility minima. Out-of-tolerance glideslope signal, due to reflections from close-in obstructions, can cause limitations, as well as protected airspace due to obstructions in the approach/missed approach area. MLS, at many locations, can resolve ILS siting constraints.

### 2. Reduced Category 1 Equivalent Minima

The inherent stability of the MLS signal has been proven to be significantly better throughout the approach spectrum, and especially at close-in ranges. The MLS decision height (DH) can likely be lower than ILS, due to the more stable MLS signal, and still provide the same level of safety and a greater probability of a successful landing.

### 3. Reduced Air Traffic Control Workload Induced Delay

Air traffic delays in terminal areas are affected by demand on the air traffic control (ATC) system. Since ATC workload is determined by total demand (i.e. instrument operations to and from all facilities), then the more rapidly the demand is served, the less ATC delays. MLS allows the average service time to be improved and reduce delays, because time reducing multiple approach paths can be used.

### 4. Curved Approach Path Savings in a Non-Radar Environment

The MLS signal coverage volume constitutes a large increase in the area covered by navigational signals over an ILS. Flying a curved or segmented path from the intercept of the MLS signal to the final approach for landing, using MLS area navigation (RNAV), the aircraft can reduce its flight time by the duration of time taken to fly the ILS procedure turn and intercept procedures.

### 5. Shortened Path Savings in a Radar Environment

In an MLS approach, the flight path is shortened as the aircraft is tracking and established on its flight track. When the aircraft arrives at its final straight-in approach segment, it is in proper orientation to complete the approach. In an ILS intercept, the aircraft must acquire the ILS signal first, and then establish a stable inbound track. The ILS flight path must be longer to allow for this stabilization on the final approach segment.

### 6. MLS Coverage of Secondary Airports

The wide-area coverage and accuracy of the MLS signal allows for the provision of non-precision approaches at secondary airports in the coverage area, as well as approaches to other runways and helipads on the same airport.

### 7. Improved MLS Reliability

Analysis indicates that MLS is more reliable than ILS with respect to outages caused by equipment failure, weather effects, and other factors which affect reliability. Therefore, MLS service will be available more often than that of ILS, and delays reduced.

### 8. Improved Safety

There are two basic safety improvements as a result of MLS service. The first is enhanced safety at sites where lower weather minima result due to the installation of MLS. The second is enhanced safety to reflect the greater reliability of MLS compared to ILS. These improved safety factors, in turn, reduce accident probability during instrument approaches.

In addition to these eight basic MLS advantages identified by FAA studies, there are a number of non-quantifiable benefits. These additional benefits are as follows:

- precision departure guidance
- increased airport capacity due to the alleviation of conflicting runway operations
- reduction in overflight effects due to MLS inherent stable signal characteristics
- noise abatement improvement
- increased landing capacity due to multiple guide path capability
- MLS data link for specific approach information
- military interoperability
- MLS will solve ILS frequency congestion (i.e. 200 channels vs. 40 channels) and FM broadcast radio interference problems
- reduced radar vectoring/communications
- increased operational flexibility

## Disadvantages:

The principle disadvantages of MLS are associated with the costs to implement an MLS program to replace ILS. ILS has been the precision approach system used throughout the world since 1946, and the transition to install MLS transmitters and receivers will be costly. Agencies, such as the U.S. General Accounting Office, are questioning whether the benefits of MLS exceed its costs.

The cost of MLS to the user is the cost of the MLS airborne equipment, installation of the equipment, prorata share of aircraft type certification, maintenance cost, equipment replacement cost at the end of economic life, and residual value of ILS equipment removed when MLS is installed. There are also life cycle costs of such devices as a flight director, MLS area navigation computer, curved approach processor, if the user wants to receive these additional MLS benefits. There is also the cost of training pilots and maintenance personnel on MLS equipment. The FAA estimates the cost to the air carriers for necessary onboard avionics will be about $15.2 billion U.S.

The MLS ground equipment cost includes not only the MLS equipment, but ancillary equipment and facilities. It also includes MLS equipment installation, MLS approach plate development and up-dating, MLS equipment replacement, MLS maintenance, and MLS training.

There are costs to maintain ILS during the transition period. These costs include ILS maintenance for both airborne and groundside equipment, as well as any ILS residual value at ILS phase out. During the transition period, both MLS and ILS costs will be incurred.

## 2.3 Available MLS Ground and Airborne Equipment

There is a growing number of equipment manufacturers interested in providing MLS equipment. The manufacturing status of MLS ground and airborne equipment is discussed below:

### GROUND TRANSMITTERS

MLS ground transmitter stations are now being, or will soon be, manufactured in Canada, United States, United Kingdom, France, Italy,Germany, U.S.S.R., Australia, and Japan.

### 1. Canada:

In Canada, Micronav Ltd. of Sydney, Nova Scotia, is currently certifying a Canadian design system. Units have been installed at Pemberton, B.C., and Port Hawkesbury, N.S. Two Micronav MLS transmitters are to be installed at Toronto Island Airport in the future.

Canadian Marconi build under licence, Hazeltine MLS. These Hazeltine Model 2500 MLS units have been installed at Nanaimo, B.C., Jasper-Hinton, Alta., Lloydminster, Alta., Fort Chipewyan, Alta., and High Level, Alta. Additional MLS units are being installed at Toronto Island Airport.

Transport Canada plans to initially install 40 MLS units, starting in 1991. Later installations will increase the total to 150. Table A, overleaf, lists the initial 40 Transport Canada MLS installations.

## Table A

## TRANSPORT CANADA MLS INSTALLATIONS

### PHASE 1 - SITE LIST (BY NETWORK IMPLEMENTATION PLAN)

| Network | Current Airport | Runway | App. Status | ICAO Plan |
|---|---|---|---|---|
| 1 | Vancouver | 08 | ILS CAT II | Yes |
| 1 | Victoria | 27 | ILS | Yes |
| 1 | Nanaimo | 16 | NDB | |
| 1 | Kelowna | 15 | LOC | |
| 1 | Kamloops | 26 | LOC | |
| 1 | Penticton | 16 | LOC | |
| 1 | Prince George | 15 | ILS | |
| 1 | Terrace | 33 | LOC | |
| 2 | Calgary | 16 | ILS | Yes |
| 2 | Edmonton Int. | 11 | ILS | Not Listed |
| 2 | Edmonton Mun. | 34 | ILS | |
| 2 | Yellowknife | 33 | ILS | |
| 2 | Norman Wells | 26 | VOR/DME | |
| 2 | Inuvik | 23 | B/C | |
| 2 | Tuktayaktuk | 09 | NDB | |
| 3 | Toronto/Pearson | 06R | ILS CAT II | Yes |
| 3 | Hamilton | 06 | ILS | |
| 3 | London | 33 | B/C | |
| 3 | Timmins | 03 | ILS | |
| 3 | North Bay | 08 | ILS | |
| 3 | Sudbury | 04 | B/C | |
| 3 | Sault St. Marie | 29 | B/C | |
| 3 | Thunder Bay | 07 | ILS | |
| 3 | Ottawa | 32 | ILS | Yes |
| 3 | Winnipeg | 18 | B/C | Yes |
| 4 | Halifax | 06 | B/C | Yes |
| 4 | Deer Lake | 07 | B/C | |
| 4 | Gander | 31 | B/C | Yes |
| 4 | Charlottetown | 10 | VFR | |
| 4 | Wabush | 01 | ILS | |
| 4 | St. John's | 11 | ILS | Yes |
| 5 | Montreal/Dorval | 06L | ILS | Yes |
| 5 | Montreal/Dorval | 06R | B/C | Yes |
| 5 | Montreal/Mira. | 06 | ILS | Yes |
| 5 | Quebec | 24 | B/C | |
| 5 | Kuvjjearapik | 22 | NDB | |
| 5 | Kuujjvak | 07 | ILS | |
| 5 | Igabut | 18 | B/C | Yes |
| 5 | Val D'Or | 36 | B/C | |
| 5 | Resolute Bay | 17T | B/C | |

## 2. U.S.A.:

The U.S. currently has two MLS manufacturers. Hazeltine Corp. has a contract with the FAA to deliver 178 Model 2600 MLS units. These units meet FAR 2721 performance criteria. Production problems have delayed the program by two years, and the first deliveries are now taking place. The first has been installed at Lebanon, NH, and soon units will be installed at Oklahama City, OK, New York, (JFK) NY, Buffalo, NY, Boston, Mass., Laconia, NH, and Manchester, NH. Production will increase to eight a month, and it is expected that all units under the current production run will be completed in 1989. E-Systems is manufacturing the DME-P subsystem, and will be first installed in the Lebanon MLS unit.

Wilcox Electric Ltd. is a second manufacturer of MLS in the U.S. This firm was recently purchased by Thompson CSF Inc,, the large French avionics manufacturer. Wilcox MLS units have been installed at Stratford, CT, East Hartford, CT, West Palm Beach, FL, Hailey, ID, and Wichita, KS.

Bendix Avioncs Inc. did manufacture, until recently, ground based units and Bendix MLS ground systems were installed at Valdez, AK, Shemya, AK, Cadillac, MI, Sturgis, MI, and Bellaire, MI.

In the U.S., a total of 1250 MLS units will be installed to replace conventional ILS, at a cost of $1.6 billion U.S. The Department of Defense plans to procure another 405 units at an estimated cost of $387 million U.S.

Table B, overleaf, shows the planned installation schedule for MLS site locations in the U.S., as at August 14, 1987.

## Table B

## SCHEDULED U.S. MLS SITE LOCATIONS

| City | State | Airport/Rwy. | Sequence |
|---|---|---|---|
| Alamosa | CO | Bergman/02 | 16 |
| Albany | NY | Albany County/28 | 100 |
| Allentown | PA | Bethlehem/24 | 173 |
| Anchorage * | AK | Int'l./06R | 80 |
| Atlanta * | GA | Hartsfield/26L | 129 |
| Atlantic City | NJ | Bader Field/11 | 176 |
| Atlantic City | NJ | FAA Tech. Ctr. Heliport | 23 |
| Baltimore | MD | BWI/15L | 39 |
| Bangor * | ME | Int'l./33 | 107 |
| Barre-Montpelier * | VT | Knapp/17 | 101 |
| Barrow | AK | WPWR Memorial/06 | 149 |
| Beaver Falls | PA | Beaver County/10 | 171 |
| Bellingham | WA | Int'l./34 | 62 |
| Belmar | NJ | Allaire/14 | 177 |
| Bethel | AK | Bethel/36 | 154 |
| Binghamton | NJ | Edwin Link/28 | 99 |
| Boston * | MA | Logan/22L | 2 |
| Boston * | MA | Logan/15R | 30 |
| Boston * | MA | Logan/33L | 29 |
| Brookings | SD | Mun./30 | 93 |
| Buffalo * | NY | Greater Buffalo/23 | 1 |
| Burbank | CA | Burbank/15 | 52 |
| Burlington * | VT | Int'l./15 | 103 |
| Burlington | VT | Int'l./33 | 102 |
| Camp Springs * | MD | Andrews AFB/19B | 42 |
| Carlsbad * | CA | McClellan-Palomar/24 | 143 |
| Charleston * | WV | Kanawha/05 | 120 |
| Charlottesville * | VA | Charlottesville/03 | 43 |
| Chicago | IL | Midway/22L | 31 |
| Chicago | IL | O'Hare/04L | 32 |
| Clarksburg * | WV | Benedum/21 | 121 |
| Cleveland | OH | Burke Lakefront/24R | 36 |
| Cleveland | OH | Hopkins/36 | 35 |
| Cold Bay * | AK | Cold Bay/32 | 153 |
| Colorado Springs * | CO | Mun./35 | 84 |
| Concord | CA | Buchanan/19R | 68 |
| Cordova * | AK | Cordova/27 | 79 |
| Cumberland | MD | Mun./23 | 122 |
| Dallas-Ft. Worth * | TX | Dallas-Ft. Worth/17R | 13 |
| Deadhorse * | AK | Deadhorse/04 | 148 |
| Denver | CO | Stapleton/17R | 18 |
| Denver | CO | Stapleton/36 | 17 |
| Des Moines | IA | Mun./05 | 90 |
| Detroit | MI | Wayne County/09 | 34 |
| Eagle | CO | Eagle County/25 | 86 |

**Table B Cont'd**

| | | | |
|---|---|---|---|
| Eugene | OR | Mahlon Sweet/34 | 75 |
| Fairbanks * | AK | Int'l./19R | 147 |
| Fayetteville | AR | Drake Field/16 | 10 |
| Flagstaff | AZ | Pulliam/21 | 15 |
| Fort Lauderdale * | FL | Hollywood/27R | 132 |
| Fort Rucker * | AL | Cairns AAF/06 | 124 |
| Fort Smith | AR | Mun./07 | 12 |
| Fort Yukon | AK | Fort Yukon/21 | 150 |
| Gainesville | FL | Regional/10 | 128 |
| Galena | AK | Galena/25 | 151 |
| Grand Canyon | AZ | Grand Canyon/21 | 136 |
| Grand Junction * | CO | Walker Field/11 | 82 |
| Grand Rapids | MN | Itasca County/34 | 92 |
| Gunnison | CO | Cunnison County/06 | 83 |
| Hagerstown | MD | Washington County/09 | 123 |
| Hartford | CT | Brainard/02 | 105 |
| Hawthorne | CA | Mun./25 | 55 |
| Hayden | CO | Yampa Valley/28 | 85 |
| Hilo * | HI | Lyman/26 | 56 |
| Hilton Head | SC | Hilton Head/21 | 126 |
| Houma * | LA | Terrebonne/18 | 45 |
| Islip | NY | MacArthur/15R | 114 |
| Ithaca | NY | Tompkins County/14 | 96 |
| Juneau | AK | Int'l./08 | 76 |
| Kansas City | MO | Downtown/03 | 89 |
| Kansas City | MO | Int'l./27 | 88 |
| Kenai * | AK | Mun./19 | 81 |
| Ketchikan * | AK | Int'l./11 | 78 |
| Key West | FL | Int'l./09 | 134 |
| King Salmon * | AK | King Salmon/11 | 152 |
| Laconia | NH | Laconia Mun./08 | 3 |
| Las Vegas | NV | McCarron/19L | 135 |
| Lebanon * | NH | Lebanon Mun./18 | 5 |
| Little Rock * | AR | Adams Field/22 | 11 |
| Long Beach | CA | Long Beach/12 | 157 |
| Long Beach * | CA | Long Beach/30 | 158 |
| Los Angeles * | CA | Int'l./06R | 50 |
| Los Angeles * | CA | Int'l./07L | 159 |
| Los Angeles * | CA | Int'l./07R | 146 |
| Los Angeles * | CA | Int'l./24L | 51 |
| Los Angeles * | CA | Int'l./25R | 160 |
| Louisville * | KY | Standford/19 | 119 |
| Manchester * | NH | Greiner Mun./35 | 4 |
| Marathon | FL | Marathon/07 | 131 |
| Medford | OR | Jackson County/32 | 65 |
| Mesa | AZ | Falcon Field/22L | 138 |
| Miami * | FL | Int'l./09R | 133 |
| Milwaukee | WI | Mitchell/25L | 33 |
| Minneapolis * | MN | MSP/11R | 95 |

**Table B Cont'd**

| | | | |
|---|---|---|---|
| Mitchell | SD | Municipal/12 | 94 |
| Moses Lake * | WA | Grant County/32R | 69 |
| Naples | FL | Municipal/22 | 130 |
| Newark * | NJ | Int'l./04R | 21 |
| Newark * | NJ | Int'l./22L | 22 |
| Newark | NJ | Newark/11 | 28 |
| New Haven * | CT | Tweed/02 | 112 |
| New Orleans | LA | Moisant/19 | 44 |
| New York * | NY | Kennedy/04L | 6 |
| New York | NY | Kennedy/13L | 24 |
| New York * | NY | Kennedy/22L | 27 |
| New York * | NY | LaGuardia/13 | 26 |
| New York * | NY | LaGuardia/22 | 113 |
| New York | NY | Wall St. Heliport | 25 |
| Nome * | AK | Nome/27 | 156 |
| Oakland | CA | Int'l./27L | 165 |
| Oklahoma City | OK | APM-150 | 7 |
| Oklahoma City | OK | FAA Academy | 8 |
| Oklahoma City | OK | FAA Depot | 49 |
| Oklahoma City | OK | FAA Depot | 9 |
| Oklahoma City | OK | Wiley Post/35R | 47 |
| Ohama | NE | Eppley Field/14L | 91 |
| Ontario | CA | Int'l./26R | 162 |
| Page | AZ | Mun./15 | 137 |
| Palm Springs | CA | Mun./30 | 58 |
| Pasco * | WA | Tri-Cities/21R | 71 |
| Patterson | LA | H.P. Williams/23 | 48 |
| Philadelphia * | PA | Int'l./09R | 174 |
| Philadelphia * | PA | Int'l./17 | 175 |
| Philadelphia | PA | Northeast/15R | 115 |
| Phoenix | AZ | Deer Valley/25L | 139 |
| Phoenix | AZ | Sky Harbor/08L | 54 |
| Phoenix | AZ | Sky Harbor/26R | 53 |
| Pitt Granville | NC | Pitt Granville/19 | 127 |
| Pittsburgh * | PA | Int'l./10L | 118 |
| Pittsburgh * | PA | Int'l./32 | 170 |
| Pittsfield | MA | Mun./26 | 108 |
| Portland * | ME | Int'l./29 | 106 |
| Portland | OR | Int'l./10L | 66 |
| Provindence * | RI | T.F. Green/23L | 111 |
| Reading | PA | Mun./13 | 172 |
| Redding | CA | Mun./16 | 67 |
| Redmond * | OR | Roberts/22 | 74 |
| Reno * | NV | Int'l./16R | 166 |
| Richmond | VA | Byrd/02 | 37 |
| Richmond | VA | Byrd/20 | 38 |
| Rochester | NY | Monroe County/10 | 98 |
| Rockland | ME | Knox County/03 | 109 |
| Rutland | VT | Rutland State/19 | 104 |

**Table B Cont'd**

| | | | |
|---|---|---|---|
| Sacramento * | CA | Metropolitan/16L | 168 |
| Sacramento * | CA | Metropolitan/34R | 169 |
| St. George | UT | Mun./34 | 140 |
| St. Mary's | AK | St. Mary's/16 | 155 |
| Salisbury | MD | Wicomico County/14 | 41 |
| Salt Lake City | UT | Int'l./34R | 87 |
| San Diego | CA | Gillespie/27R | 145 |
| San Diego * | CA | Lindbergh/09 | 144 |
| San Jose * | CA | Int'l./12R | 164 |
| San Jose * | CA | Int'l./30L | 163 |
| San Luis Obispo | CA | San Luis/29 | 61 |
| Santa Ana * | CA | John Wayne/19R | 57 |
| Santa Barbara | CA | Mun./25 | 59 |
| Santa Maria * | CA | Santa Maria/12 | 161 |
| Santa Monica | CA | Mun./21 | 60 |
| Scottsdale | AZ | Mun./21 | 141 |
| Seattle * | WA | King County/13R | 63 |
| Seattle * | WA | Tacoma/34R | 64 |
| Shreveport | LA | Regional/05 | 46 |
| Sitka | AK | Sitka/11 | 77 |
| S. Lake Tahoe | CA | Lake Tahoe/18 | 167 |
| Spokane * | WA | Int'l./03 | 70 |
| Syracuse | NY | Hancock/14 | 97 |
| Teterboro | NJ | Teterboro/19 | 116 |
| Trenton | NJ | Mercer County/24 | 178 |
| Troy | AL | Mun. | 125 |
| Tucson * | AZ | Int'l./11L | 142 |
| Washington * | DC | Dulles/01L | 40 |
| Washington | DC | National/33 | 19 |
| Washington * | DC | National/36 | 20 |
| Wenatchee | WA | Pangborn/29 | 73 |
| Wilmington | DE | New Castle County/09 | 117 |
| Worchester | MA | Mun./29 | 110 |
| Yakima * | WA | Yakima/27 | 72 |
| Yuma * | AZ | Int'l./21R | 14 |

* - ILS Co-location.

### 3. Europe:

In Europe, ICAO implementation plans indicate some 373 MLS units will be installed between 1989 and 2001 at international airports. Table C shows the number by country.

European MLS manufacturers which have under development or plan to build MLS systems of their own design or under license agreement, include Thompson - CSF of France, Standard Elektrik Lorenz AG (SEL) of Germany, Norsk Marconi of Norway, Consorzio, Naviation International and Phillips Sp A of Italy, and Plessey PLC, MEL (Phillips Electronics), and Racal Avionics, all of the United Kingdom.

In the Soviet Union, All-Union Scientific Research Institute of Radio Equipment (AUSRIRE) in Leningrad, has developed MLS transmitters to ICAO specifications, now used in their space shuttle program.

**Table C**

EUROPEAN MLS INSTALLATIONS - 1989 - 2001

| | | | |
|---|---|---|---|
| Algeria | 10 | Luxembourg | 2 |
| Austria | 9 | Malta | 2 |
| Belgium | 8 | Netherlands | 7 |
| Bulgaria | 3 | Norway | 21 |
| Cyprus | 2 | Poland | 7 |
| Czechoslovakia | 5 | Portugal | 4 |
| Denmark | 21 | Romania | 7 |
| Finland | 28 | Spain | 27 |
| France | 49 | Sweden | 20 |
| Germany (DDR) | 5 | Switzerland | 5 |
| Germany (FRG) | 26 | Soviet Union | 20 |
| Greece | 3 | Tunisia | 4 |
| Ireland | 7 | United Kingdom | 42 |
| Italy | 29 | | |
| | | TOTAL | 373 |

4. Australia:

Australian MLS development is headed by Interscan, owned by the Australian Government Australian Industry Development Corporation. Interscan has a partnership agreement with Wilcox Electric.

5. Japan:

Japan is another region where MLS ground stations are being developed. Toshiba Electric and Nippon Electric Corporation (NEC) both have developed MLS transmitters. Test units are being operated at Sendai Airport in Northern Japan.

## Airborne Receivers

In terms of airborne MLS receivers, there are also several manufacturers which have units in production or plan to have in the near future.

At this time, UNISYS (Sperry Corporation), and Bendix-King (Allied Signal Corporation) are the major suppliers of MLS receivers, with about 250 units sold at the end of 1987. Sperry manufactures the model ML Z-900 receiver, priced at $11,000 U.S. Bendix-King produces the model MLS-20A ($12,200 U.S.) and model MLS-21A ($13,000 U.S.).

Canadian Marconi has developed the CMA-2000P Microlander receiver system, built to ARINC-727 specifications. It is one of the most technically advanced MLS receivers available at a cost of about $15,000 U.S. This unit is now being certified for use on U.S. Air Force 1, the President's Boeing 747.

In terms of low cost MLS receivers, Pelorus Navigation Systems of Calgary, Alta., and Japan Radio Co. Ltd. of Tokyo have plans for low cost panel mounted receivers installed in general aviation aircraft. Japan Radio Co Ltd. have developed production receivers and the FAA is currently testing the under $2,000 U.S. receiver. Lower cost MLS receivers will assist with the transition from ILS to MLS.

## 2.4 Installation Schedule Progress

In April, 1977, the International Civil Aviation Organization (ICAO) established international operational requirements for a successor to ILS in its Report of the Seventh Air Navigation Conference. This document outlined the criteria for a new approach system. In 1978, ICAO selected the Time Reference Scanning Beam (TRSB), one of several competing types of MLS, as the standard precision landing system to replace the ILS, and in 1981 adopted a plan for transition from ILS to MLS.

Progress toward MLS implementation is being made worldwide. A number of countries are already implementing MLS and/or developing plans for transition, either individually or with other countries, as part of a regional approach. The International Civil Aviation Organization (ICAO) adopted in 1981 an ILS/MLS transition plan. The time scale of the transition program was up-dated in 1986 to extend the ILS "Protection Date" from 1995 to 1998. Every State, however, is free to determine its own plans concerning the continued service life of its ILS units within the overall ICAO time-scale. The following are the prime factors which a State takes into consideration in developing its own implementation plan.

1. Recognition of the ICAO ILS "Protection Date".
2. Recognition of the need to provide MLS as soon as practicable where requirements for ILS cannot be met for operational, technical, or economic reasons.
3. Recognition of the need to retain at least the existing level of ILS service until 1998.
4. Recognition of the need for early introduction of MLS to gain experience in an operational environment.
5. Recognition of the need to avoid an unduly long transition period.
6. Recognition of the need for regional and inter-regional planning based on air route networks.
7. Recognition that some of the potential MLS benefits will not be realizable until all users are MLS equipped.

ICAO's All Weather Operations Panel (AWOP) has been meeting on a regular basis to oversee the MLS transition plan. Technical and operational guidance material for "basic" MLS operations have been developed. This material included such subjects as criteria for collocated ILS/MLS, initial critical/sensitive areas definition, continuity of service, and software integrity testing/criteria. The AWOP focus is now turning to advanced MLS operations. Late in 1989, the materials and documents developed by the working groups will be reviewed and recommendations made. This meeting will essentially complete ICAO's efforts to prepare the required MLS international standards and guidance material.

The U.S. MLS implementation program, after considerable delay, is now underway, with MLS production ground equipment now being installed at several locations in the U.S. Northeast region.

It is expected that the first phase of the U.S. MLS program for 178 units will be completed by 1990. The U.S. Congress has not approved the second phase.

The Canadian MLS program, like the U.S. program, has experienced delays. It is expected that MLS equipment tests will be completed in 1989, with the first Transport Canada installations being underway in 1991. Installation of MLS units to replace ILS will take place throughout the 1990's.

The European installations of MLS units will start in 1989, and continue right through to 2001. Most of the installations are scheduled to take place in the 1993-1996 time period.

It is expected that other regions of the world will schedule their MLS installations in the late 1990's, to take advantage of the later technology being developed by the more advanced countries, such as the U.S., Canada, Europe, and Japan.

## 3. NEED FOR PRECISION APPROACH AT PEMBERTON

Whistler Resort is one of North America's fastest growing recreational areas, and demand for air service is a result of this recreational development. This chapter outlines the facilities at Whistler. It also assesses air traffic demand and the need for an instrument approach into the nearby Pemberton Airport. Figure 3, overleaf, shows the location of the Pemberton Airport.

The Pemberton Airport is owned and operated by the Corporation of the Village of Pemberton. The Airport began in 1978 as a small dirt airstrip and over the past ten years has been developed by the Village and the governments of Canada and British Columbia into an airport capable of accommodating scheduled airline service. Over $5 million has been invested in airport facilities, including a 4,000' x 100' (1,219 m. X 30 m.) paved runway, paved apron, aircraft fuel installation, weather station and microwave landing system. Future plans indicate an additional $10.5 million to be invested in airport facilities, including an air terminal building, automobile parking, approach and runway lighting, and commercial lot development.

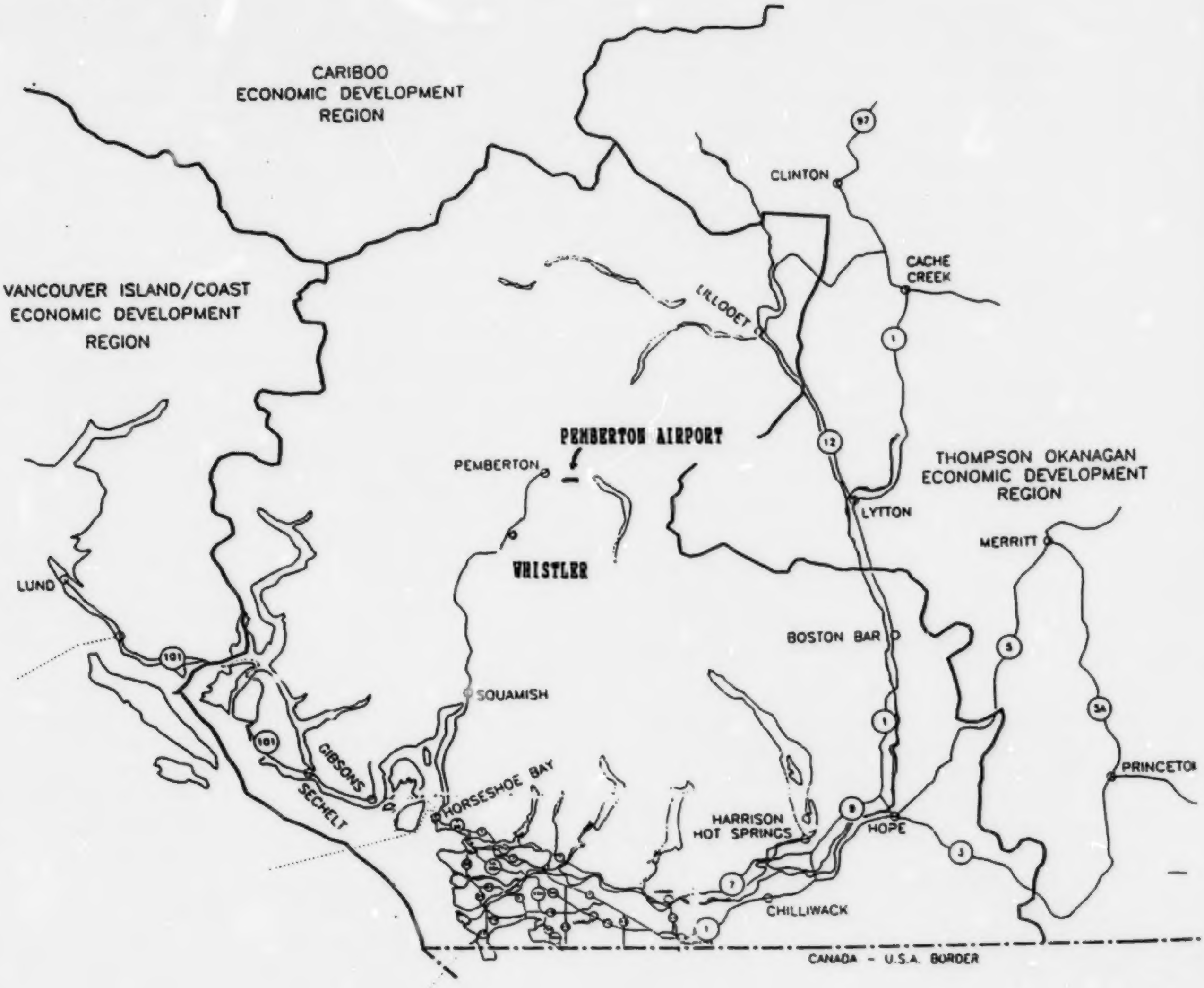
AirBC, an Air Canada alliance air carrier, which provides regional air service throughout British Columbia, Alberta and Washington State, plans to serve the Pemberton Airport. It has National Transportation Agency (formerly Canadian Transport Commission) licensed authority to service Pemberton/Whistler from Vancouver or Seattle on a regular scheduled basis. The service will be operated by a 50 seat deHavilland DHC-7 STOL aircraft, the only available aircraft which is capable of handling steep approach and missed approach flight profiles.

### 3.1 Whistler Resort Development

Air travel demand for air service to the Pemberton Airport will be generated by the Resort Municipality of Whistler, located some 38 Km south of Pemberton on Highway 99. The Resort Municipality was established in 1975 and was the first resort municipality to be established in Canada. It has been developed into a world class, year round, recreational destination resort.

To date nearly one billion dollars has be invested in resort facilities, including the following:

Figure 3
Location of Pemberton Airport


CARIBOO
ECONOMIC DEVELOPMENT
REGION
VANCOUVER ISLAND/COAST
ECONOMIC DEVELOPMENT
REGION
THOMPSON OKANAGAN
ECONOMIC DEVELOPMENT
REGION
PEMBERTON AIRPORT
PEMBERTON
WHISTLER
97
CLINTON
CACHE CREEK
LILLOOET
1
12
LYTTON
MERRITT
LUND
101
BOSTON BAR
5
SQUAMISH
101
GIBSONS
SECHELT
HORSESHOE BAY
1
5A
PRINCETO
HARRISON HOT SPRINGS
8
HOPE
3
7
CHILLIWACK
1
CANADA - U.S.A. BORDER

## Ski Facilities:

Combined ski facilities on Whistler and Blackcomb Mountains provide over 180 marked and groomed ski runs served by 28 lifts. Whistler Mountain has the greatest vertical drop in North America, at over 5200'. In the 1987/88 ski season, both mountains recorded over one million skiers, a 25% increase over the previous ski season.

Whistler Mountain has just completed a $19 million high speed gondola, to compete with the $25 million investment Blackcomb made in 1987 in providing a new gondola, restaurant and lodge facilities on the mountain as well as the first T-bar service on a glacier in North American, on Horstman Glacier. Both mountains have a daily capacity of 25,000 skiers.

## Accommodations:

There are more than 40 accommodation properties ranging from deluxe hotels to hostels, with over 1,500 rooms available. Of these 40, 26 are hotel accommodations. In addition, there are another 1,500 rooms in private chalets for short or long term rentals. In recent months several hotels have been built or expanded, including the Fairways Hotel, Nancy Green Lodge, Delta Mountain Inn expansion and the Listel Whistler Hotel. Near completion are the Lake Placid Lodge, LeChamois and the Glacier Lodge. Plans are being developed for a new Fitzsimmon Creek Lodge. The largest complex under construction is the first phase of Canadian Pacific Hotel's Chateau Whistler. The hotel construction cost for this phase is $70 million and when completed in the fall of 1989, will have 337 rooms. A further 550 rooms can be added at a future date.

## Condominiums:

Townhouse and condominium construction underway will add another 225 units at a cost of $25 million. Most of the new construction is taking place on a 254 acre property at the foot of Blackcomb Mountain on the benchland above Whistler Village. Whistler Mountain Ski Corporation has applied for rezoning of rural land near Whistler Creek. If fully developed, up to 3,000 bed units could be built in this area.

Convention Facilities:

The Whistler Convention Centre, since its completion in 1985, has hosted a number of world class conventions. It has also helped to attract visitors to Whistler during the Spring and Fall shoulder demand tourist periods. The 100,000 sq. ft. facility can accommodate up to 2,000 people attending conventions.

Recreational Facilities:

In addition to the world class skiing facilities, including heli-skiing, Whistler has a full range of recreational facilities. These include tennis, horseback riding, wind surfing, hiking, biking, water slides and golf. A second 18-hole golf course designed by Robert Trent Jones is being built by Canadian Pacific Hotels, and will join the existing Arnold Palmer designed course.

Entertainment:

There are over 30 restaurants and 15 night spots, offering a wide variety of food and entertainment for visitors to Whistler.

Other Developments:

Recently, Meager Creek Development Corporation, in conjunction with the Australian Pennant Group, announced it had acquired a geothermal lease at Meager Creek, 45 km. northwest of Pemberton. Electricity will be developed from the geothermal well to sell to B.C. Hydro and Power Authority. A first phase development of $15 million will be made to have electricity available by 1991. A $100 million luxury resort/spa facility will also be developed at the hot springs, as well as other recreational facilities.

## 3.2 Air Traffic Demand

The Whistler Resort Association estimates that in the 1987/88 ski season over 135,000 visitors used overnight accommodations in the Whistler area. A large percentage of these overnight visitors were from Eastern Canada,

Washington State, California and Japan. It is expected a large percentage of these visitors used air travel to reach Vancouver or Seattle and connected to surface transportation to complete their journey to Whistler. These more distant visitors are the key target markets for the planned AirBC air service to Pemberton Airport. Using convenient connections at Vancouver

International Airport and Seattle-Tacoma International Airport with other domestic and international airlines, AirBC will develop an air service which caters to the recreational oriented visitor to Whistler.

Table D presents the projected passenger volumes which are expected to use the proposed AirBC scheduled service. Both summer and winter passenger volumes are shown. The Vancouver - Pemberton service is expected to be three times a day during the winter and once a day during the summer. The Seattle - Pemberton route would be operated twice a day during the winter. The projections are shown for a fifteen year period 1990-2005. It is projected the air service will attract 49,000 enplaned/deplaned passengers in 1990, and increase to 75,000 passengers in 2005. The annual growth rate is 2.9%.

Passenger load factors are expected to be 50.6% during 1990 and raising to 77.4% by 2005 assuming that no additional flight frequency is added during the time period of the forecast.

## 3.3 Mountainous Terrain, Weather Conditions, and Instrument Approaches

### Terrain

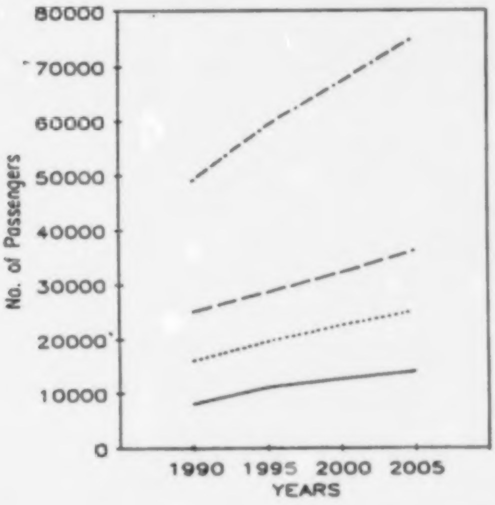
The Pemberton Airport is located on an island at the joining of the Lillooet and Green Rivers in the Pemberton Valley. The valley is surrounded by the Coast Mountain Range. Immediately to the south of the airport is Mount Currie with a height of 8364', over 7600' above the valley floor. To the north is Mount Ronayne at 7450' and Place Glacier at 8550'. On the west is Mount Ipsoot at 8400' and on the east Mount Matier at 9000'. All these mountains are within a 10 NM radius of the airport. Only the valley which follows the Lillooet/Green Rivers and adjoining Lillooet Lake offers relatively flat terrain. This long, narrow valley corridor provides the only possible instrument approach and missed approach pattern for the Pemberton Airport. Since the valley is as narrow as one mile and twists and turns twice during it's length, a precision landing aid is the only approach aid which could be contemplated to provide the necessary accuracy and obstacle clearance limitation safety. Figure 4 shows the surrounding terrain in relationship to the Pemberton Airport.

## Table D

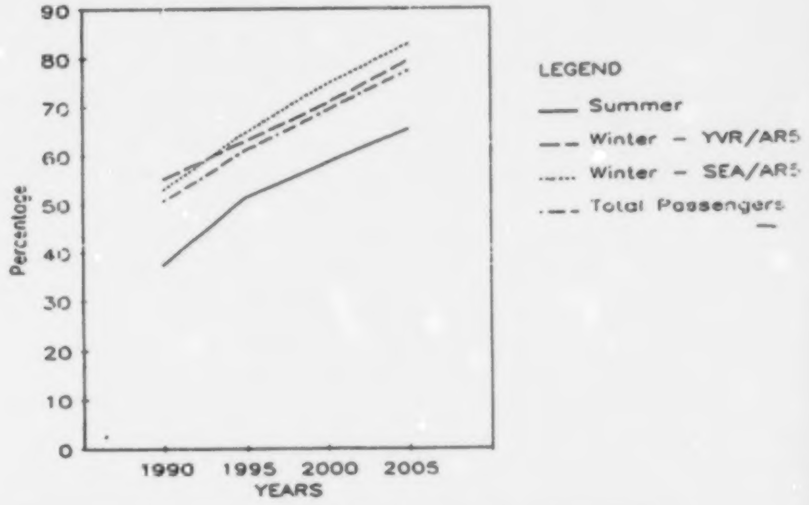
### PEMBERTON AIRPORT
### PROJECTED PASSENGER VOLUME & LOAD FACTORS

| ROUTE-SEASON | | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|
| VANCOUVER - PEMBERTON (YVR - AR5) | | | | | |
| Summer | Pax. | 8,000 | 11,000 | 12,500 | 14,000 |
| | Seats | 21,400 | 21,400 | 21,400 | 21,400 |
| | L.F. | 37.4% | 51.4% | 58.4% | 65.4% |
| Winter | Pax. | 25,000 | 28,500 | 32,000 | 36,000 |
| | Seats | 45,300 | 45,300 | 45,300 | 45,300 |
| | L.F. | 55.2% | 62.9% | 70.6% | 79.5% |
| Total | Pax. | 33,000 | 39,500 | 44,500 | 50,000 |
| | Seats | 66,700 | 66,700 | 66,700 | 66,700 |
| | L.F. | 49.5% | 59.2% | 66.7% | 75.0% |
| SEATTLE - PEMBERTON (SEA - AR5) | | | | | |
| Winter | Pax. | 16,000 | 19,500 | 22,500 | 25,000 |
| | Seats | 30,200 | 30,200 | 30,200 | 30,200 |
| | L.F. | 53.0% | 64.6% | 74.5% | 82.8% |
| GRAND TOTAL | Pax. | 49,000 | 59,000 | 67,000 | 75,000 |
| | Seats | 96,900 | 96,900 | 96,900 | 96,900 |
| | L.F. | 50.6% | 60.9% | 69.1% | 77.4% |

PEMBERTON AIRPORT
PROJECTED PASSENGER VOLUME



PEMBERTON AIRPORT
PROJECTED PASSENGER LOAD FACTORS



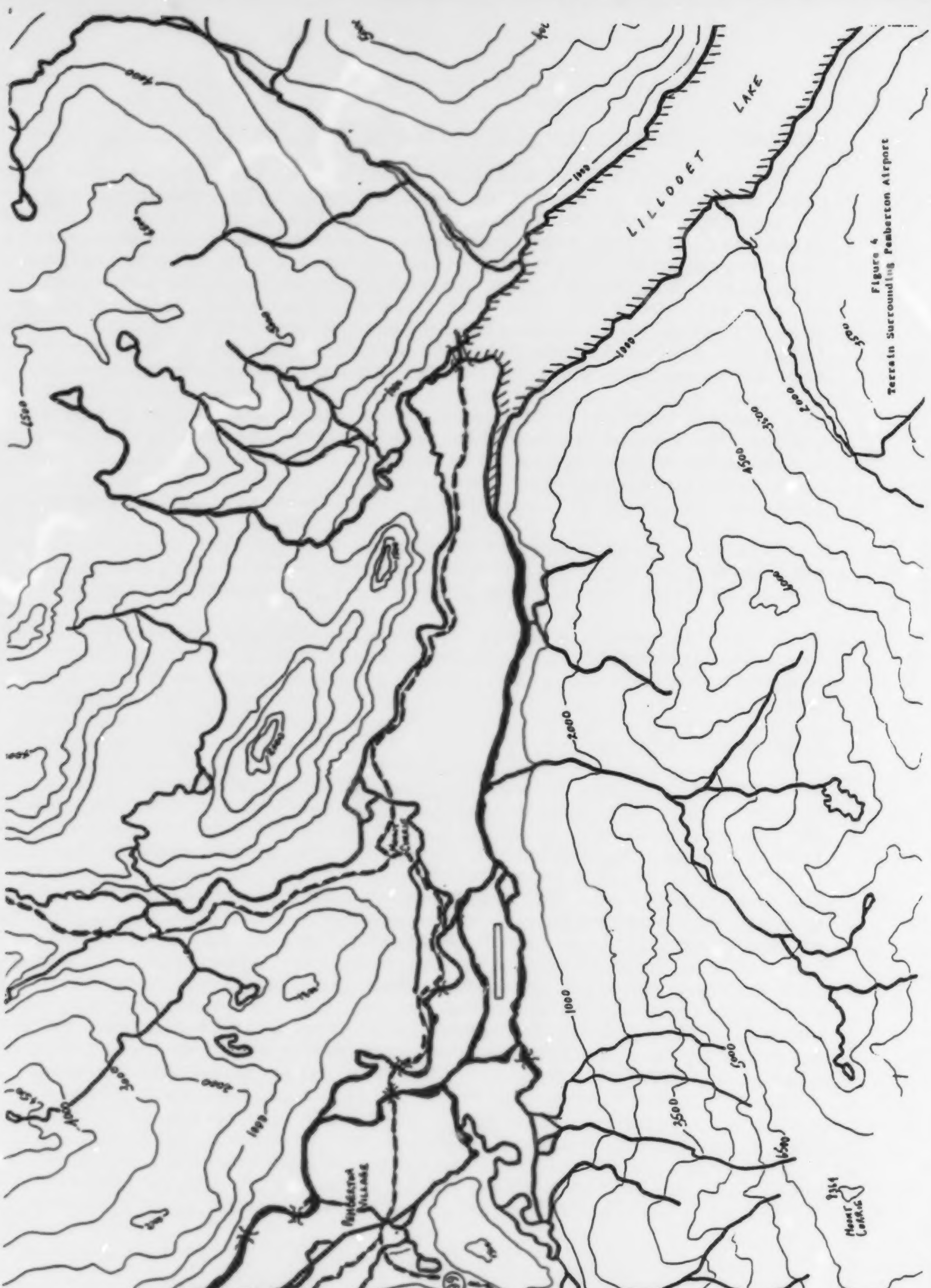

LILLOOET LAKE
PEMBERTON VILLAGE
MOUNT CURRIE
8354
99
1000
1500
2000
3000
3500
4500
5000
6500

Figure 4
Terrain Surrounding Pemberton Airport

## Weather

Mountain valley weather conditions also point out the requirement for a precision landing aid. The Pemberton Valley is located where the Pacific Coastal low pressure systems mix with the Interior high pressure systems, to produce unstable weather. Pacific Coastal weather systems frequently bring heavy rainfall and snowfall just to the west of the Pemberton Valley as the systems rise over the Coastal Mountains. These storms are frequently accompanied by strong westerly winds. When Interior high pressure periods occur there is a drying trend and, on occasion, strong out-flow winds from the north and east.

During periods of Pacific Coastal storms and westerly winds, the ceiling can be reduced, due to cloud cover and visibility reductions during rain or snow showers. Interior high pressure periods improve the ceiling visibility but increase the risk of river fog occurring in the Spring and Fall.

Since the surrounding mountains are glacier covered, local strong anabatic winds can be created due to the temperature change between the glacier fields and the warmer valley below.

The uncertain weather conditions in the Pemberton Valley area dictate that an instrument landing system is required in order to provide reliable, all weather air service throughout the year.

## Instrument Approaches

There are two types of precision landing aids available; conventional instrument landing system (ILS) and the newer microwave landing system (MLS). The ILS, however, could not be installed in the Pemberton Valley. The surrounding mountains would cause reflections and disrupt the ILS localizer signal. The height of the surrounding mountains in relation to the elevation floor would not allow a standard 3° ILS glideslope to be designed within a required obstacle clear zone. The MLS, on the other hand, is not as severely affected by signal reflections from mountainous terrain, and the signal beam coverage area can be modified to provide the precision accuracy needed. The MLS glide- slope also can be modified to permit approaches in excess of 3°, which permits steep mountain valley approach procedures to meet obstacle clearance limitations.

## 3.4 MLS Role Model and Pemberton MLS Development

### Rocky Mountain Airways

The concept for using a precision approach in a mountain valley setting was originally developed by Rocky Mountain Airways (now Continental Express) based in Denver, Colorado.

The airline was established in the late 1960s as a small commuter air carrier serving communities in the mid-west region with light twin-engine aircraft. With the acquisition of six deHavilland DHC-6 Twin Otter aircraft in the early 1970's, the company began to examine the potential of serving the ski resort market in Colorado. The analysis indicated that a reliable all-weather service was required to provide an air service which could compete with the private automobile. Conventional instrument aids were not appropriate for this mountainous terrain. The unpressurized Twin-Otter was also not an ideal aircraft for the type of service envisioned, but its short field performance and ability to operate steep approaches was clearly a distinct advantage in providing a reliable service.

Military surplus Singer-Talar microwave landing system units became available. These early MLS units had a mechanical scanning beam instead of the later technology time referenced scanning beam, but did operate on the C band microwave frequency range and had a variable glideslope. Rocky Mountain Airways purchased all the surplus Singer-Talar MLS units. The ground units were installed at Aspen, Steamboat Springs, and Vail (Avon). At Avon, Rocky Mountain Airways also had to construct their own STOL airport, along with night lighting. Airborne receivers were installed in the Twin Otters to start the first MLS/STOL air service to these Colorado resort areas.

Rocky Mountain Airways placed an order for the first delivery position for the new deHavilland DHC-7 aircraft. Like the Twin Otter, the DHC-7 had superior STOL flight capabilities but it was pressurized and could carry up to 50 passengers. The first Rocky Mountain Airways DHC-7 aircraft was delivered on January 18, 1978 and began revenue service on February 3rd. The MLS instrument system and the STOL capabilities allowed the service to start with a dispatch reliability of 98.5%, in the carrier's busiest month. Within the first year the air carrier reached 100% dispatch reliability while operating 9.9 hours a day, 7 days a week, over very short stage lengths. Some 4,250 flights were flown at an average flight time of 40 minutes. Some 240,000 passengers were carried, a 66% increase over the previous year. In December of 1979 the second deHavilland DHC-7 was delivered and a third was ordered for delivery in 1982.

Rocky Mountain Airways today operates six DHC-7 aircraft, and three Twin Otters, providing frequent service to a number of communities and resorts in the mid-west from their Denver hub. About 450,000 passengers are carried annually.

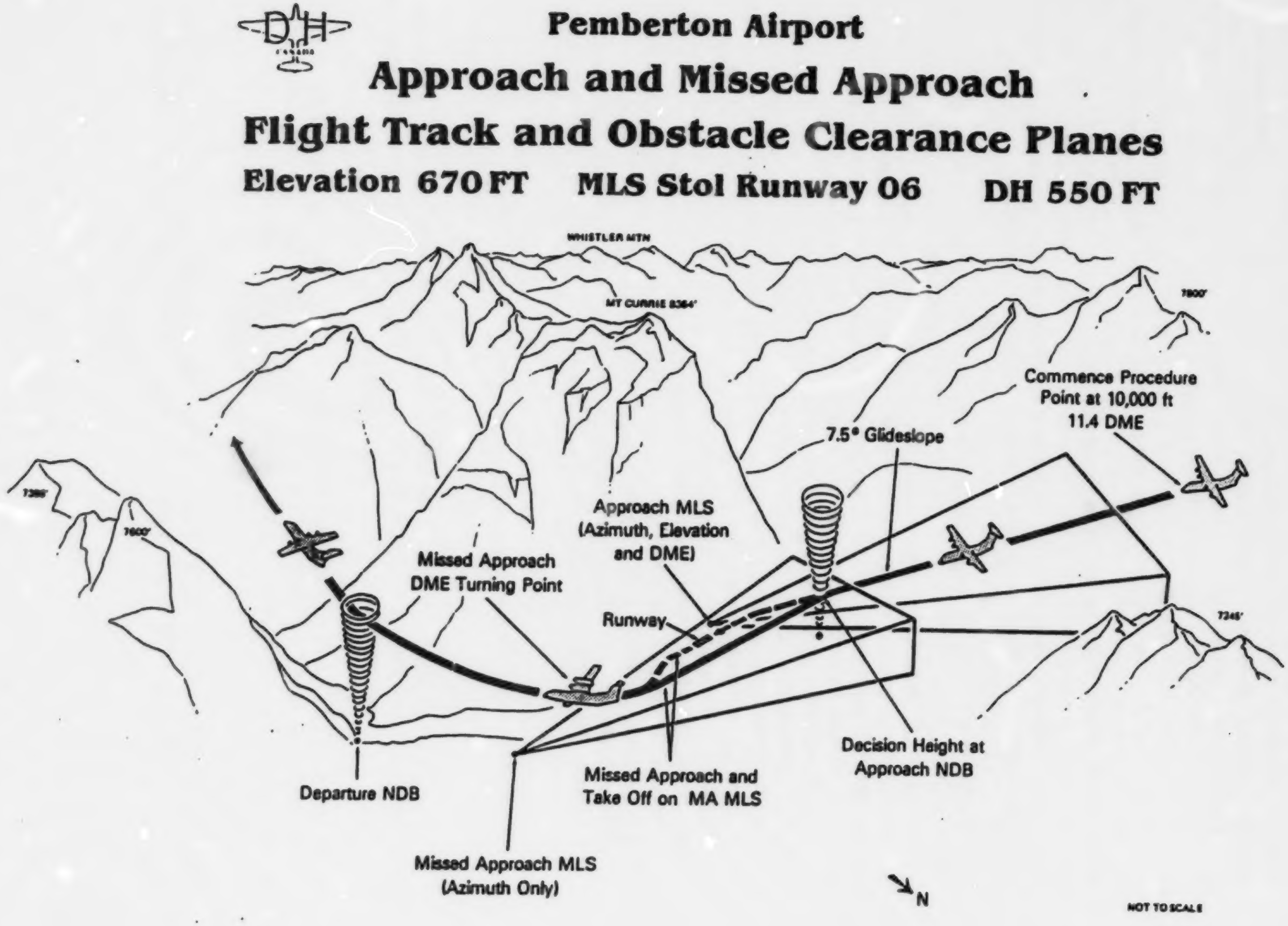
## MLS Development

The Village of Pemberton became aware of the possibilities of receiving an air service using MLS/STOL technology at a 1979 British Columbia Aviation Council seminar on STOL technology, at which Rocky Mountain Airways was represented in a panel discussion. Discussions followed with deHavilland Aircraft of Canada and AirBC by the Village, to develop a similar concept for Pemberton. In 1983, deHavilland proposed a preliminary concept of an MLS approach for the Pemberton Airport, for consideration by the Village and AirBC. This preliminary approach is shown in Figure 5, overleaf. In January of 1984, AirBC and the Village visited Rocky Mountain Airways in Denver and Vail to observe the MLS/STOL operation. Later, on March 6, 1984, deHavilland demonstrated the STOL capabilities of the DHC-7 at the Pemberton Airport, using a company demonstration aircraft. The runway at that time was a short, dirt strip. Micronav Ltd., a manufacturer of MLS ground transmitters, linked with deHavilland to refine development of the MLS concept, and to provide an estimate of the cost for the proposed navigation system. A joint proposal for funding an MLS project was presented by AirBC, Village of Pemberton, deHavilland, and Micronav to the Federal and Provincial governments in May 1984.

In 1985, the Province of British Columbia (under the Air Transportation Assistance Program - ATAP) and the Government of Canada (under the Industrial and Regional Development Program - IRDP) agreed to jointly fund the $2.17 million capital cost of the MLS system and related navigational aids at the Pemberton Airport. On August 1, 1985 the Village of Pemberton placed an order with Micronav ltd. to supply and install, on a "turn-key" basis, the MLS System. Construction began in the Fall of 1985.

In the meantime, AirBC who had operated an extensive fleet of small wheel and float aircraft in the early 1980's, including the Twin Otter, had determined that a fleet consolidation was required, as well as a scheduled route structure instead of a charter organization. This plan required a fleet of pressurized aircraft with turbine engines to serve this type of route network on a regular basis. Additional capacity was also needed. An evaluation of several types of aircraft was made by AirBC before deciding on the deHavilland DHC-7. The first DHC-7 was delivered in June of 1983, and was first operated to Bella Bella on the B.C. Coast. In October, AirBC became a CP Air

Figure 5
Preliminary Pemberton Approach


Pemberton Airport
Approach and Missed Approach
Flight Track and Obstacle Clearance Planes
Elevation 670 FT
MLS Stol Runway 06
DH 550 FT
WHISTLER MTN
MT CURRIE 8364'
7800'
7280'
7600'
7245'
Commence Procedure Point at 10,000 ft 11.4 DME
7.5° Glideslope
Approach MLS (Azimuth, Elevation and DME)
Missed Approach DME Turning Point
Runway
Decision Height at Approach NDB
Missed Approach and Take Off on MA MLS
Departure NDB
Missed Approach MLS (Azimuth Only)
N
NOT TO SCALE

partner and started operating the DHC-7 between Vancouver and Victoria airports.

Recognizing the STOL and MLS possibilities after the visit to Rocky Mountain Airways in early 1984, discussions followed between deHavilland and AirBC on the installation of MLS airborne equipment on the DHC-7 and DHC-6 aircraft. Both Canadian Marconi and Bendix-King were briefed on the needs for airborne MLS receivers and price quotes were requested. Bendix-King was selected, since their receiver had already been certified by the FAA and by Transport Canada, and they could offer a guaranteed delivery date.

DeHavilland and AirBC realized that the Pemberton MLS/STOL approach was unique and would require Transport Canada certification of, not only the MLS equipment, but likely the installation on the DHC-7 and the special flight procedures, and flight crew training needed to operate the DHC-7 aircraft in a mountain valley approach system. It was predicted that the certification process would require a considerable number of flight hours, engineering research and development, and coordination between Transport Canada and other agencies. AirBC/deHavilland submitted an unsolicited proposal to Supply and Service Canada in April of 1986 for support funds for development flight testing. The $1,351,725 proposal was denied. A revised proposal was submitted by AirBC in November of 1986. This subsequent proposal for funding consideration was substantially reduced in scope, particularly the engineering resource aspects and coupled autopilot requirement. This second proposal for $361,000 was accepted in March, of 1987. Acceptance of the proposal initiated the Pemberton MLS/STOL Flight Demonstration Project.

## 4. ADVISORY REVIEW COMMITTEE

An Advisory Review Committee was established to oversee the project. This chapter discusses the purpose of the Committee, and its members. The chapter also outlines the project management and public relations aspects of the MLS/STOL Flight Demonstration Project.

### 4.1 Purpose of the Advisory Review Committee

An Advisory Review Committee was established for the Pemberton MLS/STOL project to provide a broadly based committee composed of various interested parties concerned with the MLS certification who could provide on-going advice to the project.

The first meeting of the Advisory Review Committee was held March 31, 1987 in the Pemberton MLS/STOL Project office at Vancouver International Airport. This meeting took the form of a workshop, in order to seek from the committee a series of questions and answers on the project and the certification process. A consensus was formed as to the work tasks to be conducted, and who should conduct the work tasks. The meeting was chaired by the Transportation Development Centre. The following project queries were reviewed by the committee:

1) What are the immediate objectives and what are longer term objectives?

2) Who are the participants who have a role in assuring a successful project outcome?

3) What ground equipment is essential for the precision landing system to be operational and what is needed for site certification?

4) What airborne equipment is needed for the operation of the aircraft under IFR conditions and what is needed to certify the aircraft for IFR operations into Pemberton?

5) What flight procedures should be used in the IFR approach and departure at Pemberton, how will the pilots be trained, and what needs to be done to obtain flight crew certification?

6) What criteria will be accepted for the final form of the approach, departure and missed approach profiles?

7) What data collection instrumentation will be incorporated into the aircraft and how will it provide integrated results?

8) What are the roles and responsibilities of all the Advisory Review Committee participants in relation to the above?

Discussions took place on each of the queries raised, with regard to priority, work tasks, necessary liaison, time sequences between work tasks, and other elements. Appendix A provides the objectives discussed at this first meeting, as well as responsibilities for the various program activities.

A second Advisory Review Committee meeting took place on July 28, 1987. This meeting was held at the conclusion of the main test program, just prior to Transport Canada's initial flight test. This important meeting discussed a number of issues related to the flights which had been conducted to date, and remaining work tasks in the program.

The initial flight test program to be flown by Transport Canada was outlined by Airworthiness, noting approach profiles to be conducted and other specific tests.

Pacing items and the Airworthiness process were highlighted during the meeting, as well as system redundancy requirements. It was agreed that in order to ensure system redundancy needs, that the TDC would initiate a separate navigation risk analysis study.

A further Advisory Review Committee meeting was held on October 19, 1987. This progress meeting outlined the work tasks which had been completed since the initial flight test flown by Transport Canada during the summer. The focus of the meeting was on the back azimuth problem, and steps needed to complete the project. A technical sub-group was formed to work on the back azimuth reception problem, composed of AirBC, Micronav, Bendix-King, and Transport Canada MLS Project Office and Facilities Engineering.

## 4.2 Members of the Advisory Committee and Liaison

The members of the Advisory Review Committee include the following:

- Transportation Development Centre, Project Officer (Chairman)
- AirBC - Project Coordinator
- AirBC - Flight Operations
- AirBC - Avionics/Technical
- Transport Canada, Airworthiness, Ottawa
- Transport Canada, Airworthiness, Pacific Region
- Transport Canada, MLS Program Coordinator, Ottawa
- Transport Canada, Air Navigation Service, Pacific Region
- Transport Canada, Facilities Engineering, Pacific Region
- Transport Canada, Regulation, Pacific Region
- Transport Canada, Air Carrier Inspection, Ottawa
- Transport Canada, Air Carrier Inspection, Pacific Region
- Micronav Ltd., Project Engineer
- Bendix-King Avionics, Technical Representative
- deHavilland Aircraft of Canada, Special Projects
- B.C. Ministry of Transportation and Highways, Air Policy
- Village of Pemberton, Mayor
- Department of Regional Industrial Expansion
- Department of Supply and Services

Liaison between the Pemberton MLS/STOL Flight Demonstration Project and the Advisory Review Committee was maintained by the Project Coordinator and the Transportation Development Centre. A Transportation Development Centre RAC (Responsibility, Authority, Communications) Matrix was developed to demonstrate the various tasks to be conducted, the various agencies contributing advice, and the liaison required between agencies. The matrix established areas of prime responsibility, authority for approval of the task and communication required between the agencies in the approval process. Figure 6 presents the RAC Matrix.

## Figure 6
## RAC Matrix (Responsibility, Authority, Communications)

| | TDC Project Officer | Air BC Coordinator | Flight Operations | Avionics | Administration | Pacific Avionics/DAR | Test Support | Bendix | Micronav | De Havilland | Village of Pemberton | Province of B.C. | Transport Canada (Pacific) Coordinator | Air Navigation Requirements | Telecom | Airworthiness | Air Carrier | Air Traffic Services | Transport Canada (Ottawa) MLS Project Team/FESD | Airworthiness | Advisory Review Committee |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MILESTONE #1 | | | | | | | | | | | | | | | | | | | | | |
| Advisory Review Committee Formation | ● | ○ | | | | | | | | ◁ | ◁ | ◁ | ◁ | | | | | | | | |
| Work Task Outline | ▣ | ● | ○ | ○ | ○ | | | | | | | | | | | | | | | | ▶ |
| Installation of Avionics | | ○ | | ● | | ○ | | ○ | | ◁ | | | ◁ | | | ▣ | | | | ▣ | |
| Flight Development Profile | | ● | ○ | | | | | | | | | | | ◁ | | ▣ | | | ◁ | ▣ | |
| Flight Development Tests | | ○ | ● | | | | | | | ○ | | ○ | | ◁ | | ▣ | ○ | | ◁ | ▣ | |
| Flight Procedure Evaluation Program | | ○ | ● | | | | | | | ◁ | | | | | | | ○ | | | | |
| Data Collection and Analysis | | ● | ○ | | | | ○ | | | ◁ | | | | | ◁ | | | | | | |
| Verify Ground Equipment | | ● | | | | | | | ○ | | | | | | ◁ | | | | | | |
| Develop Milestone #1 Report | ▣ | ● | | | ○ | | | | | | | | | | | | | | | | ▶ |
| MILESTONE #2 | | | | | | | | | | | | | | | | | | | | | |
| Initial Flight Tests | | ○ | ● | | | ◁ | | ◁ | | ◁ | | ○ | ◁ | ◁ | ◁ | | ○ | | | | |
| Pemberton Flight Development Tests | | ○ | ● | | | | | ◁ | ◁ | ◁ | ○ | | ◁ | ◁ | ◁ | ▣ | ○ | ◁ | ◁ | ▣ | |
| Develop Milestone #2 Report | ▣ | ● | | | ○ | | | | ◁ | | | | | | | | | | ◁ | | ▶ |
| MILESTONE #3 | | | | | | | | | | | | | | | | | | | | | |
| Complete Flight Procedure Evaluation Program | | ○ | ● | | | | | | | ◁ | | | | | | ▣ | | | | | |
| Flight Procedure Evaluation Ground Course Set-Up | | ○ | | | | | | | | | | | | | | | | | | | |
| Evaluation of Flight Procedure Program Progress | | ○ | ● | | | | | | | | | | ◁ | | | | □ | | ◁ | | |
| Develop Milestone #3 Report | ▣ | ● | | | ○ | | | | | | | | | | | | | | | | ▶ |
| MILESTONE #4 | | | | | | | | | | | | | | | | | | | | | |
| Data Collection & Preliminary Analysis | | ● | ○ | ○ | ○ | | ◁ | | | | | | | | | | | | | | |
| Test Development Evaluation | | ● | ○ | | | | | | | ◁ | | | | | | ▣ | | | | | |
| Complete Data Evaluation & Submit to Transport Canada | | ● | ○ | | | | | | | | | | ◁ | □ | | | □ | | ◁ | ▣ | |
| Remove Data Recording Equipment & Return | | ● | | ● | | | | | | | | | | | | | | | | | |
| Prepare Draft Report | ▣ | ● | ○ | ○ | ○ | | | | | | | | | | | | | | | | ▶ |
| Final Report and Acceptance | ■ | ● | | | ○ | | | | | | ◁ | ◁ | ◁ | | | | | | ◁ | | |
| Delivered & Functional | | | | | | | | | ● | | ◁ | | | | | | | | | | |
| Certification Tests (Ground Navaids) | | | | | | | | | ● | | | | | | | | | | ▣ | | |
| Calibration Tests (Ground Navaids) | | | | | | | | | | | | | | ● | | | | | | | |
| Commissioning (Ground Navaids) | | | | | | | | | | | ◁ | | | ▣ | | | | | | | |
| Operation/Maintenance (Ground Navaids) | | | | | | | | | | | ● | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| Flight Manual Supplement | | | ● | ○ | | ○ | | | | ○ | | | | | | | | | | | |
| Operations Manual | | | ● | | | | | | | | | | | | | | | | | | |
| Training Program | | | ● | | | | | | | | | | | | | | ▣ | | | | |
| Operations Certification Addendum | | | ● | | | | | | | | | | | | | | ▣ | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| Approach Plate | | | ○ | | | | | | | ● | | ○ | | | | | | | | | |
| DHC-7 IFR 7.7° Approach | | | ○ | | | | | | | ● | | | | | | | | | | ▣ | |

RESPONSIBILITY ○
Prime Performance ●
Limited Performance ○

AUTHORITY □
Must Approve: Executive ■
Must Recommend For Approval □
Must Approve: Professional ▣

COMMUNICATIONS ◁
Must be Consulted (Discussion) ◀
Must Be Informed (Discussion) ◁
Must Advise or Guide (Written) ▶
Must Be Advised (Written) ▷

PEMBERTON MLS STOL DEMONSTRATION PROJECT - PROJECT MANAGEMENT CONTROL

## 4.3 Project Administration

Project administration was handled by AirBC. Total responsibility for project management was the Project Manager, AirBC's Director of Flight Operations. In turn, day-to-day project administration was handled by the Project Coordinator, an Air BC sub-contractor. The Project Coordinator was responsible for overall coordination/ liaison, arranging flight demonstration tests, data collection and compilation, coordination of data analysis, public relations, writing of Milestone Reports, scheduling and budgeting items of the project. Advisory Review Committee secretarial functions were also conducted by the Project Coordinator. Direct liaison between the Project Coordinator and Transportation Development Centre, Project Officer was maintained throughout the project, to ensure project administration was on-going. A special Pemberton MLS/STOL Project Office was established by AirBC in its Vancouver International Airport Training Building.

## 4.4 Public Relations

Public relations developed into a project task when the flight demonstration schedule began. Since the MLS/STOL application at Pemberton is unique, it attracted considerable media and professional attention, as it is one of the few mountain valley precision approaches in the world using MLS/STOL technology. It also has a back azimuth for departure and missed approach, which is the only one of its kind to date.

In 1985, with the announcement that construction would begin on the MLS ground based system at Pemberton, Vancouver and Whistler news media carried the concept. Attention to the project was further heightened during EXPO 86 at Vancouver, when a scale model of the approach and missed approach was exhibited by deHavilland at the Canada Pavilion. Several international professionals saw this model and requested information.

During the Flight Demonstration Project in 1987, articles on the MLS/STOL project were frequently displayed in Vancouver and Whistler newspapers. Radio and television features were also conducted. Several aviation trade magazines also featured the project and the flight testing procedures.

Professional interest was shown by the FAA and NASA in the U.S., ICAO in Montreal, Governments of Austria, China, and Norway, and representatives of airlines such as Cathay Pacific Airlines, Horizon Air, Delta Airlines and Air Canada. Pilot organizations such as Canadian Air Line Pilots' Association, International Air Line Pilots' Association, and American Air

Line Pilots' Association also expressed an interest in the project, and sent representatives to see the MLS installation and discuss the flight procedures with AirBC.

Public relations interest in the project continues today, with enquiries as to the state of project certification and the establishment of a regular scheduled route service.

## 5. CERTIFICATION PROCESS

Transport Canada is responsible for the certification of the total Pemberton MLS system, both the ground and air elements of the system. Certification is required in order to ensure that the equipment and procedures used in a scheduled air service meet safety standards in order to protect the travelling public. This chapter briefly outlines the certification process.

### 5.1 Ground Equipment Certification

There are two basic certification steps for the MLS ground equipment; equipment type certification and equipment installation approval.

#### Type Certification

MLS ground equipment is designed to meet Transport Canada DTA-1000 standards (ICAO SARPS Annex 10 and FAA FAR 171 Parts J and G). These standards include the following:

- integrity and continuity of service
- failure-free operation
- independent monitor verification
- built-in DME/P growth capability
- redundant configuration
- remote maintenance and monitoring system
- approach, departure, missed approach guidance
- antenna and tower frangibility
- system accuracy requirements
- meets environmental specifications

Micronav Ltd. has designed their MLS ground transmitter to meet ICAO, Transport Canada and FAA specifications. Units which have been installed at Port Hawkesbury and Pemberton are prototype MLS units, but can be retrofitted to meet certified standards. Micronav has submitted its MLS to Transport Canada for type approval in March 1987. Micronav's MLS has undergone software documentation verification and environmental testing. Under a Transportation Development Centre contract, Micronav is currently finalizing the MLS design and software operating performance. Qualification testing will begin in a few months with a March 31, 1989 target date for complete certification. After modifications are made, the Pemberton MLS system will be the first operational certified MLS of Micronav Ltd., followed by the planned Toronto Island Airport installation.

### Installation Certification

The Pemberton MLS approach aid system installation also has to be approved by Transport Canada. This approval includes approval of each component installation of the system, including the non-directional beacons (NDB's), MLS azimuth, MLS elevation, DME, Radio Frequency (RF) communication links, monitoring devices, as well as the signal trans-mission coverage of the equipment, frequency identification and other elements of the system. To date, the field equipment installation has been approved by Transport Canada for most of the components. RF communications, remote monitoring and final site approvals will be completed in the near future.

Flight tests of the ground equipment were conducted by Transport Canada in the summer of 1987. The flight tests were accomplished in a Transport Canada King Air equipped with Bendix 20 receivers. These tests indicated that good signals in space were being received throughout the coverage volume in both the front azimuth and back azimuth areas. It should be noted that the Bendix 20 is not capable of receiving both a front azimuth and back azimuth at the same time, therefore either the front or back azimuth was shut down while the other unit was being tested. The flight tests indicated that the system should not experience difficulties in achieving full certification once the system was fully installed with retrofit modifications. Transport Canada plans to conduct a final flight check of the MLS ground equipment with a specially equipped deHavilland DHC-8 navigational calibration aircraft. This aircraft is equipped with dual Bendix-King 21A receivers, similar to those used by AirBC in the DHC-7. Certification of the Micronav Ltd. MLS equipment installed at Pemberton will be to a Transport Canada Class "B" standard. (i.e. public use/ private facility).

### 5.2 Airborne Equipment Installation

The airborne MLS equipment also requires certification. The Bendix-King MLS 21A have been type certified by the FAA and Transport Canada, but not the installation in the

DHC-7 aircraft. Included in the MLS receiver installation is the wiring harness to connect the aircraft's power supply to the receivers, dual (fore and aft) antennae, antenna pre-amplifier, signal splitter and lead wiring to connect receivers in the avionics chassis (underfloor). MLS control display units, panel annunciators, and instrumentation interface in the aircraft cockpit, are also part of the installation package.

Some previous work had been done by deHavilland on MLS installations, using a DHC-7 demonstration aircraft equipped with MLS receivers. Engineering drawings were available for this installation as a basic guide to AirBC, but the complexity of the Pemberton MLS approach, particularly with the back azimuth procedure, resulted in a unique design installation. Pacific Avionics and Instruments Ltd. was contracted to design and install the MLS airborne receivers in the AirBC flight demonstration aircraft. Pacific Avionics, in turn, subcontracted a Design Approval Representative (DAR) to develop the necessary engineering drawings needed by Transport Canada for approval. Installation began in April 1987. The installation of the wiring harness and antennae required cutting into a pressurized hull and other structural/engineering difficulties. Installation of the receivers and the interface with the flight instrument (HSI, etc.) was relatively straight forward. It was the control display unit, panel annunciator, and "go around" button on the control yoke which required considerable experimentation to determine the best type of display, colour of annunciator lights, and display location in the cockpit. The panel annunciator had to be manufactured by AirBC. Since components of the panel annunciator were non-standard, certification required additional time since each sub-component in the design had to be approved. Certification of the MLS installation was completed by June 1987.

## 5.3 Initial Transport Canada Flight Tests

Transport Canada conducted an initial series of flight tests as part of the certification process in July 1987. These tests were divided into three principle areas of investigation:

1) Signal coverage area envelopes and basic evaluation of the approach procedure

2) Approach, departure, and missed approach flight configurations under normal, unusual and emergency procedures

3) Cockpit workload, ease of MLS control head, interface with flight instruments, cockpit visual reference, and aircraft flight supplement procedures.

A Transport Canada engineering test pilot and observer flew the various flight tests, accompanied by AirBC flight crew and technical personnel. Chapter 9.0 describes the initial airworthiness flight tests in more detail.

The results of the initial Transport Canada flight tests indicated that the MLS avionics met signal reception standards. The DHC-7 handled the steep approach, departure and missed approach flight profiles under all normal, unusual and emergency conditions. Cockpit workload and crew coordination was good, and no special procedures will be required. Raw data from the flight instruments is acceptable for MLS tracking error, and the MLS does not have to be coupled to the Flight Director/ Autopilot, a more complex engineering procedure.

Because the Pemberton facility will be a private MLS facility (Class "B", rather than Class "C") it was suggested the 1985 ICAO software format be used instead of the 1981 ICAO format. The new software format provides actual magnetic track indication on the control head, rather than the existing 0± heading. The following modifications were recommended to be made prior to a final flight test by Transport Canada:

1) The interim design of the MLS annunciator/ switching panel is confusing in its function and will have to be changed.

2) The control yoke mounted BAZ selection button ("go-around" button) must be moved to the outboard side of the control yoke.

3) The BAZ available light should not indicate the presence of a BAZ signal with the BAZ HSI flags in view whenever BAZ has been selected.

4) Front AZ signals should not be present in the missed approach areas.

5) MLS identification signal not as published for the approach.

6) Flaps 15 degrees, gear down aircraft configuration will probably not provide adequate course capture and tracking characteristics under critical conditions. (i.e. Flaps 25 degrees recommended).

## 5.4 Final Airworthiness Flight Check

The final airworthiness flight check in the total certification process will occur upon completion of the ground and air certification steps outlined in the previous subsections. The major pacing item is the elimination of the front azimuth signal in the back azimuth cover area. This overlapping of signals and related problems are causing momentary flags in the BAZ coverage area. The problem is more fully described in chapter 10.

The following outlines the remaining steps for final certification:

1) Micronav to complete approval of the ground MLS type certification with Transport Canada.

2) Micronav to update and modify the Pemberton ground installation.

3) Micronav to change ground equipment Basic Dataword 7 to double BAZ signal transmission.

4) Micronav to install additional ground Out-of-Coverage Indicator (OCI) antenna at front AZ site to reduce reflections.

5) Bendix-King to modify receiver software to accept doubling of Basic Dataword 7 transmission.

6) AirBC to install permanent Panel Annunciator and other recommendations made during the initial flight tests.

7) AirBC to flight test C-GXPO to determine if BAZ flagging problem is solved.

8) Transport Canada certification of the Micronav Ltd. MLS system at Pemberton, including Transport Canada flight test.

9) Final Airworthiness flight check.

Chapter 12 discusses the final flight check program in detail.

## 6. RESEARCH WORK PLAN

This chapter provides an overview of the research work plan that was used to guide the MLS/STOL Flight Demonstration Project.

### 6.1 Milestone Format

It was considered that due to the complexity of the project and the uncertainties of obtaining various certification approvals within the scheduled parameters, that a milestone type of format be used to administer the project. The milestone format provides the flexibility to adjust the work tasks and the project schedule to adapt to changing requirements of the project. The milestone format allows the development of major research components within the overall project as well as the development of specific work tasks within each major research component.

Four basic milestones were established at the start of the project. Completion of each milestone resulted in a progress report to the Advisory Review Committee and the Transportation Development Centre. The Technical Report, herein, represents the conclusion of Milestone 4, the final milestone in the current project. The milestones, and their major work tasks as outlined in the Research Work Plan, are provided below:

#### Milestone 1 - Demonstration Set-Up

Task 1 - Develop a detailed work plan, activity schedule, cash flow projections, project management control and documentation procedures and apply the RAC matrix method to organizing and informing all participants in the project.

Task 2 - Engineer and install MLS airborne equipment and obtain airworthiness approval.

Task 3 - Develop flight profiles supplying support documentation for glideslope, approach chart plates and a DHC-7 flight manual supplement to be submitted to Transport Canada.

Task 4 - Develop a detailed description of the technical aspects of the demonstration testing including:

1) the flight profiles to be flown
2) the failure modes to be simulated
3) the cockpit procedures to be developed
4) the data collection process
5) the documentary support for Transport Canada

Task 5 - Develop flight procedures evaluation program

Task 6 - Evaluate data collection system needs and acquire space and equipment necessary to collect, analyze and display

Task 7 - Monitor ground equipment installation and readiness

Task 8 - Prepare and submit Milestone 1 report.

## Milestone 2 - Flight Testing

Task 9 - Undertake initial flight tests to assess complete flight profiles of approach, missed approach and departure and to assess critical engine out profiles.

Task 10 - Undertake main flight test program at Pemberton to develop and evaluate:

1) transition onto approach
2) transition to missed approach
3) departure procedures

Task 11 - Prepare and submit Milestone 2 report.

## Milestone 3 - Flight Procedures

Task 12 - Complete flight procedures and submit to Transport Canada.

Task 13 - Establish ground school course including visual aids.

Task 14 - Evaluate training program.

Task 15 - Prepare and submit Milestone 3 report.

Milestone 4 - Data Collection and Analysis

Task 16 - Undertake data collection related to on-board performance of MLS received signal and position in space of aircraft throughout test program, ensuring that data from various sources can be correlated.

Task 17 - Analyze data, evaluate results and develop output information during initial flight testing.

Task 18 - Complete data collection analysis and evaluation and submit to Transport Canada.

Task 19 - Return all equipment used in tests to rightful owners.

Task 20 - Prepare and submit report describing all project results, conclusions, and recommendations in accordance with TDC reporting requirements.

## 6.2 Modifications to the Work Plan

During the course of the Pemberton MLS/STOL Flight Demonstration Project, the Research Work Plan was modified as to the work tasks conducted. These modifications are discussed below:

Milestone 1 tasks were completed without any significant changes to the research work plan.

During Milestone 2 Flight Testing, it was recognized that some changes had to be considered to the work plan. These considerations included:

1) Flight delays due to non-VFR flying days. These delays impacted on the availability of a flight test aircraft, test equipment, and needed personnel on hand to conduct the flight tests.

2) Requirement for additional AirBC avionics/technical personnel to assist during the flight test program. All MLS equipment, as well as test equipment, had to be installed before each flight and removed after the demonstration flight. It required at least six hours to have the equipment on board before the test flight and four hours to remove and store the equipment.

3) Provision had not been originally made to have Micronav Ltd. technicians available in the field while the tests were being conducted. Personnel are required to determine the status of the ground MLS equipment, and to make adjustments to the ground equipment during the flight tests, to ascertain if problems encountered during flight testing were airborne or ground related.

4) Back azimuth flagging problem developed into a major research project which was not in the original research work plan. This item developed into a pacing item with regard to certification of the project.

Milestone 3 was also modified. Based on the favourable results of the initial airworthiness test flights, the requirement for a detailed MLS/STOL ground school course and training program, as well as the evaluation program was reduced considerably in scope. In its place, additional flight tests were performed in order to find a solution to the BAZ flagging occurrences.

Milestone 4 was conducted essentially as outlined in the research work plan. Items which were affected by flight operations in the back azimuth coverage area, however, required modifications to the data collection and analysis. It also affected documentation to be submitted to Transport Canada in the approval process.

### 6.3 Project Schedule

The MLS/STOL Flight Demonstration Project was originally contemplated to be a six month research project. Various delays, however, substantially extended the schedule, particularly with the advent of BAZ flagging which could not be rectified as part of the current project.

It was intended that in the first month of the project, April 1987, the work task outline, avionics installation and flight development profile would be completed. The avionics installation was delayed due to changes in engineering drawings, delays in receiving equipment, and airworthiness required modifications to the MLS airborne equipment being installed.

Flight development tests were subsequently delayed until late June and July. The aircraft C-GXPO was originally slated to be taken off scheduled line service at the end of March for the avionics installation and flight tests in April and May. It was to be available on an exclusive basis for the tests and to return to line service, by the first week in June. The project delays required that the test aircraft return to revenue line service, and was available only for flight tests during the weekends, or late afternoon on certain weekdays. This aircraft limitation, in turn, extended the project schedule.

Weather related problems also delayed the project schedule. All flights had to be conducted in VFR weather conditions, and frequent unsettled weather posed numerous flight demonstration cancellations.

The flight procedure evaluation work task was extended, due to additional flight tests and research undertaken in an attempt to solve the BAZ flagging problem. This required additional test equipment to be located and used to analyze the problem, as well as several meetings with various technical experts to develop possible solutions. These additional research elements extended the project into the Winter of 1987 and Spring of 1988.

Data collection and analysis during the initial and main test flight period (July, August 1987) was analyzed in the Fall of 1987. The complete data analysis, however, could not be finished due to the unsolved BAZ flagging situation, nor could completion of the necessary documentation for the airworthiness certification process. The Transport Canada certification process was subsequently seriously delayed, well beyond the original project schedule.

# 7. RESEARCH TEST EQUIPMENT

The MLS/STOL Flight Demonstration Project required research test equipment in order to conduct the flight tests. This chapter describes the research test equipment used.

## 7.1 Research Aircraft

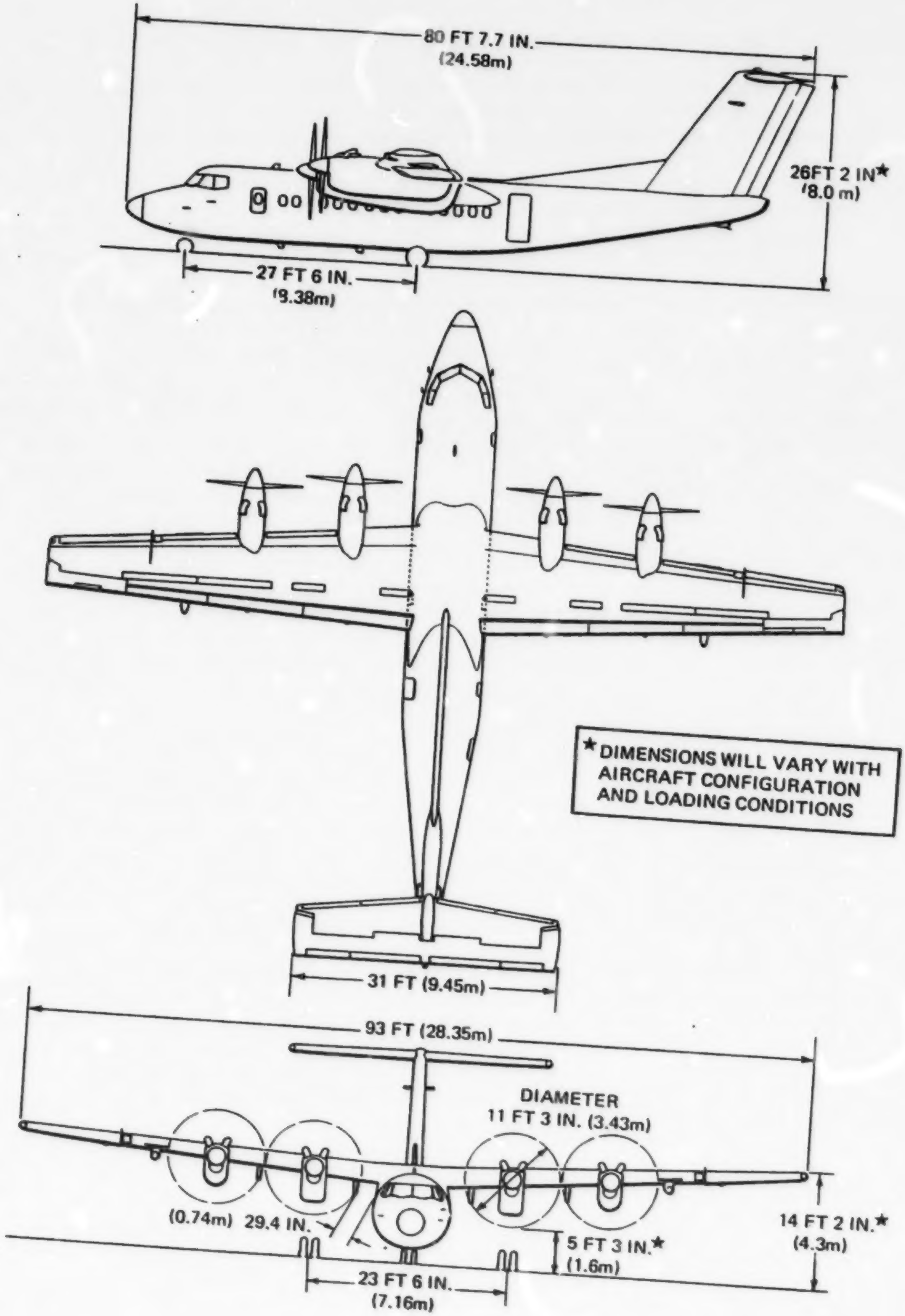
The principal aircraft used for flight testing was an AirBC owned and operated deHavilland DHC-7-102. C-GXPO (Serial Number 21) was selected from the fleet of six AirBC DHC-7's for the research aircraft. In addition to C-GXPO, AirBC deHavilland DHC-6-100 aircraft, C-FJCL (Serial Number 62), and C-FIOH (Serial Number 64), which are both equipped with MLS receivers, were used for certain test flights, particularly in testing BAZ signal transmission problems.

The deHavilland DHC-7 (Dash 7) is powered by four Pratt & Whitney PT6A-50 turboprop engines, and can carry up to 50 passengers in its pressurized/air conditioned cabin. The aircraft type was first flown on March 27, 1975, and was certified in the Transport Category in compliance with FAR 25, and eligible for operations in day and night VFR, IFR, and icing conditions. Airworthiness certification was May 2, 1977. The aircraft has short take-off and landing (STOL) characteristics, allowing the aircraft to conduct steep approach and departure angles, and operate from air strips at gross take-off weight with a balanced field length of only 2260 ft. (688 m.) (i.e. ISA, SL, Flaps 25°). Figure 7, overleaf, shows the dimensions of the DHC-7 aircraft.

The maximum take-off weight of the DHC-7 is 44,000 lbs., providing a maximum payload of 11,400 lbs. With 50 passengers and baggage (9,500 lbs.), long range cruise speed, and IFR reserves, the aircraft has a payload/range of 690 NM. The maximum cruise speed (VMo) is 231 kts. (8,000 ft. TAS). The maximum operating altitude with passengers is 20,400 ft.

Enroute rate of climb at gross take-off weight (SL) is 1,200 fpm, and is reduced to 700 fpm with three engines operating. The enroute ceiling with three engines (MCP, 1.6% climb), is restricted to 14,800 ft. The aircraft has excellent performance characteristics at altitudes below 15,000 ft., with performance decreasing significantly at altitudes higher than 15,000 ft.

Figure 7
Dimensions of the DHC-7 Aircraft


80 FT 7.7 IN.
(24.58m)
26FT 2 IN★
(8.0 m)
27 FT 6 IN.
(8.38m)
★DIMENSIONS WILL VARY WITH AIRCRAFT CONFIGURATION AND LOADING CONDITIONS
31 FT (9.45m)
93 FT (28.35m)
DIAMETER
11 FT 3 IN. (3.43m)
(0.74m) 29.4 IN.
5 FT 3 IN.★
(1.6m)
14 FT 2 IN.★
(4.3m)
23 FT 6 IN.
(7.16m)

The large, hydraulically powered, rudder, roll spoilers, and the double slotted wing flap system comprising a single fore flap, and three trailing flaps, provide excellent flight manoeuvrability. The landing gear operating speed (VLo) is 147 kts., and the flaps extended speed (VFe) is as follows:

| | |
|---|---|
| Flaps 15° | 147 kts. |
| Flaps 25° | 120 kts. |
| Flaps 45° | 110 kts. |

The minimum control speed (maximum 5° bank, one engine out, remaining engines at take-off power, and flaps 25°), is 65 kt. IAS. The slow approach speed and the flight control manoeuvrability contribute to the STOL performance of the aircraft.

## 7.2 Aircraft Equipment

The deHavilland DHC-7 Flight Manual should be referred to for detailed information on aircraft equipment. This sub-section describes aircraft equipment relevant to the Pemberton MLS/STOL project.

### 7.2.1 Flight Control System

The flight control systems interface with the MLS receivers to provide navigation guidance.

C-GXPO is equipped with a Sperry SPZ-700 Automatic Flight Control System, which integrates autopilot/ flight director/air data systems. The system provides a full complement of horizontal and vertical flight guidance modes, including radio guidance modes, RNAV tracking, and air data oriented vertical modes. When engaged and coupled to the flight director, the SPZ-700 will control the aircraft using the commands generated by the flight director computer/controller. When engaged and uncoupled from the flight director, manual pitch and roll commands can be inserted using the touch control steering or the pitch wheel and turn knob. When the autopilot is coupled to the flight director, the instruments act as a means to monitor the performance of the autopilot. When the autopilot is not coupled to the flight director, the same modes of operation are available for flight director only. The pilot manoeuvres the aircraft to satisfy the flight director commands (i.e. raw data inputs).

The guidance information from the flight director is key for conducting an MLS instrument approach. The components of the flight director are as follows:

1. Integrated Attitude Director Indicator (CDI) - displays pitch and roll attitude cross pointer flight director commands, glideslope deviation, localizer deviation, radio altitude, inclinometer and attitude test switch. Go Around (GA) and Decision Height (DH) annunciator, and appropriate flags are also shown. (Figure 8, overleaf, and text).

2. The Horizontal Situation Indicator (HSI) - combines numerous displays to provide a display of aircraft position. The indicator displays course deviation and glideslope deviation. It also functions as a heading reference, giving aircraft heading with respect to magnetic north. (Figure 9 and text).

3. Instrument Remote Controller - has heading select and course select.

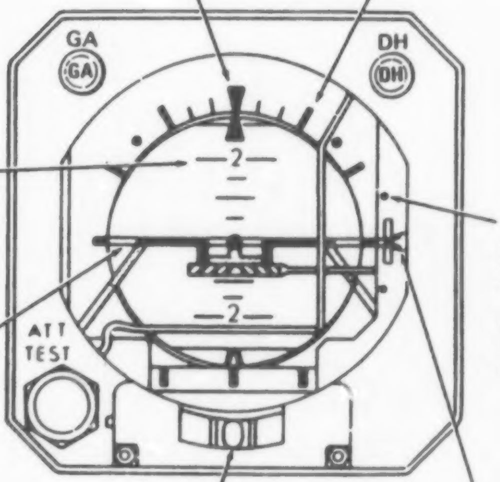
4. Flight Director Mode Selector - contains all mode select buttons and annunciation of flight director modes. (Figure 10 and text - note MLS mode).

5. Flight Director Computer - contains all computation and mode selection electronics.

### 7.2.2 Weather Radar

The weather radar installed in C-GXPO was used as part of the flight demonstration tests at Pemberton. The terrain mapping features of the radar were used as a cross-check reference for aircraft position during the flight profile. The mapping techniques of the radar worked well in the Pemberton Valley, due to the sharp terrain features, particularly in delineating Lillooet Lake in the missed approach segment. A Primus-40 weather radar system is used. It is a light-weight, solid state system which detects and locates various types of weather, as well as terrain mapping. The antenna is located in the radome on the nose of the fuselage. The radar indicator is located on the centre console in the aircraft cockpit, and the operating controls are grouped around the weather indicator.

**Figure 8**
**Integrated Attitude Director Indicator**



**ROLL ATTITUDE INDEX**

**FIXED ROLL ATTITUDE SCALE**

Scale is marked from zero to 10, 20, 30, and 60 degrees left and right. Roll attitude is indicated by index mark on attitude sphere.

**ATTITUDE SPHERE**

Displays both pitch and roll attitudes of the airplane by its physical relationship to the fixed airplane symbol.

**GLIDE SLOPE SCALE**

During ILS operation each dot represents 0.4° displacement from glide slope beam centerline. The two dots shown are equivalent to the inner dots on the HSI.

**AIRPLANE SYMBOL**

Stationary symbol of airplane. Pitch and roll attitudes are displayed by relationship between airplane symbol and attitude sphere.

**GLIDE SLOPE POINTER**

Indicates vertical deviations of airplane from glidepath. The moveable pointer represents the centerline of the glidepath. The pointer is biased out of view if a valid glide slope signal is not present or when a back course mode is selected.

**INCLINOMETER**

Displays slip and skid information for aid in coordinating turns.

ATTITUDE DIRECTOR INDICATOR – HZ-444

# Instruments

## HZ-444 ATTITUDE DIRECTOR INDICATOR

The HZ-444 Attitude Director Indicator (ADI) combines the attitude sphere display with lateral and vertical computed steering bars to provide the pilot commands required to intercept and maintain a desired flight path. It also contains an eyelid display, expanded localizer, glide slope, rising radio altitude bar, and inclinometer. The indicator has integral blue-white lighting, go-around, and decision height annunciators.

### ATTITUDE SPHERE

Moves with respect to the symbolic aircraft reference to display actual pitch and roll attitude. Pitch attitude marks are in 5-degree increments on a blue and brown sphere. These colors are the most contrasting and acceptable display colors from a human factors standpoint.

### SYMBOLIC MINIATURE AIRCRAFT

Serves as a stationary symbol of the aircraft. Aircraft pitch and roll attitudes are displayed by the relationship between the fixed miniature aircraft and the movable sphere. The symbolic aircraft is flown to, and the center "fuselage" red dot aligned with, the command bars to satisfy the commands of the flight director mode selected.

### ROLL ATTITUDE INDEX

Displays actual roll attitude through a movable index and fixed reference marks at 0, 10, 20, 30 45, 60, and 90 degrees.

### "EYELID" DISPLAY

Surrounds the attitude sphere and provides positive attitude identification by means of a blue "eyelid," which always shows the relative position of the sky, and a brown "eyelid," which always shows the relative position of the ground. The eyelids maintain the proper ground-sky relationship, regardless of the position of the sphere. This facilitates fast recovery from unusual attitudes.

### FLIGHT DIRECTOR COMMAND BARS

Display computed steering commands to intercept and maintain a desired flight path. Always fly the symbolic miniature aircraft to the intersection of the flight director bars. The horizontal bar displays pitch commands, and the vertical bar displays roll commands.

### GLIDE SLOPE SCALE AND POINTER

Displays aircraft deviation from glide slope beam center only when tuned to ILS frequency and a valid glide slope signal is present. Aircraft is below glide path if pointer is displaced upward. The glide slope dot represents 75 microamperes displacement or approximately 0.4 degree deviation from the beam centerline. Category II window information (± 35 microamperes) is displayed as a green area on the glide slope scale.

### RADIO ALTITUDE BAR

For added backup during the critical approach phase of flight, absolute altitude above the terrain is displayed below 200 feet by a barber-pole radio altitude bar. The bar appears at 200 feet and moves toward the miniature aircraft as the aircraft descends toward the runway, contacting the bottom of the symbolic aircraft at touchdown.

### EXPANDED LOCALIZER

Is displayed by the localizer pointer whenever a valid localizer signal is available. Raw localizer displacement data from the navigation receiver is amplified approximately 7-1/2 times to permit the localizer pointer to be used as a sensitive reference indicator of the aircraft's position with respect to the center of the localizer. It is normally used for assessment only, since the pointer is too sensitive to fly throughout the entire approach. During final approach, the pointer serves as an indicator of the Category II window. Full-scale deflection of the expanded localizer pointer is equal to 20 microamperes or 1/4 degree of beam signal.

### INCLINOMETER

Gives the pilot a conventional display of aircraft slip or skid, and is used as an aid to coordinated maneuvers.

### ATTITUDE TEST SWITCH

Operates the attitude self-test of the indicator. When pressed, the sphere will show approximately a 20-degree right bank and a 10-degree pitch-up attitude, and the ATT warning flag will appear.

### GO-AROUND ANNUNCIATOR

Illuminates when go-around mode has been selected.

### DECISION HEIGHT ANNUNCIATOR

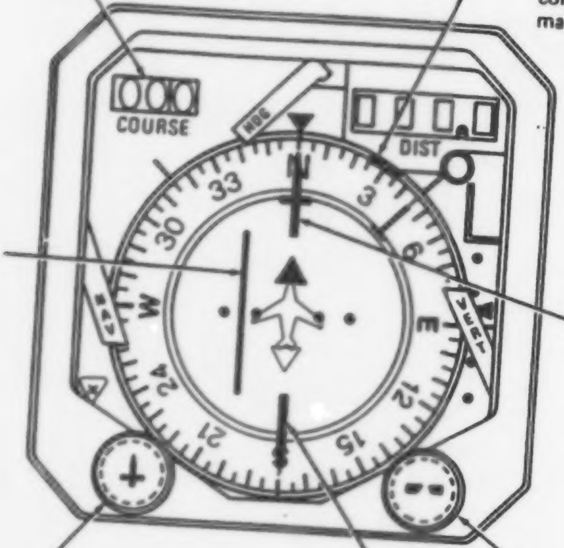
Illuminates when aircraft descends below selected decision height as set on the radio altimeter indicator.

### VERTICAL GYRO FAST-ERECT SWITCH

This remotely mounted momentary switch provides for manual erection of the vertical gyro and is spring-loaded in the OFF position. The switch should be pressed and held in the ON position to erect the gyro only when the aircraft is in stable level flight. When the switch is in the ON position and the gyro is up to speed, the gyro will erect at about 20 degrees per minute. Pitch axis movement will only be seen when the switch is released.

Figure 8 Cont'd

## Figure 9
## Horizontal Situation Indicator



**COURSE COUNTER**

Provides a digital readout of a selected course in degrees.

**HEADING BUG**

This notched orange heading bug is positioned on the rotating heading dial by the heading knob, and displays preselected compass heading. In the heading mode the ADI command bar will display the proper bank commands to turn to and maintain this selected heading.

**COURSE DEVIATION BAR**

Indicates deviation in degrees from a selected course center line during VOR or ILS operation.

**COURSE POINTER**

Indicates selected course.

**HEADING SELECTOR KNOB**

Sets the heading bug (Not on RD-500A)

**COURSE SELECTOR KNOB**

Sets the course pointer and course counter (Not on RD-500A)

**RECIPROCAL COURSE POINTER.**

Indicates reciprocal of course selected.

HORIZONTAL SITUATION INDICATOR – RD-500

## RD-445/RD-450 HORIZONTAL SITUATION INDICATOR

The RD-445/RD-450 Horizontal Situation Indicator (HSI) combines numerous displays to provide a map-like presentation of the aircraft position. The indicator displays aircraft displacement relative to VOR, localizer, and glide slope beam, and heading with respect to magnetic north.

### AIRCRAFT SYMBOL

A fixed miniature aircraft symbol corresponds to the longitudinal axis of the aircraft and lubber line markings. The symbol shows aircraft position and heading with respect to a radio course and the rotating heading dial.

### ROTATING HEADING DIAL

Displays gyro-stabilized magnetic compass information on a dial which rotates with the aircraft throughout 360 degrees. The azimuth ring is graduated in 5-degree increments.

### LUBBER LINE MARKS

Fixed heading marks at the fore and aft positions.

### AZIMUTH MARKS

Fixed at 45-degree bearings throughout 360 degrees.

### HEADING BUG AND HEADING KNOB

The notched orange heading "bug" is positioned on the rotating heading dial by the heading knob, and displays preselected compass heading. The "bug" rotates with the heading dial so the difference between the "bug" and the fore lubber line index is the amount of heading error applied to the flight director computer. In the heading mode, the ADI roll command bar will display the proper bank commands to turn to and maintain this selected heading.

### COURSE POINTER AND COURSE KNOB

The yellow course pointer is positioned on the heading dial by the course knob to select a magnetic bearing that coincides with the desired VOR radial or localizer course. Like the heading "bug," the course pointer also rotates with the heading dial to provide a continuous readout of course error to the computer. When one of the radio modes is selected, the roll command bar in the ADI will display bank commands to intercept and maintain the selected radio course.

### COURSE DEVIATION BAR

Represents the centerline of the selected VOR or localizer course. The aircraft symbol pictorially shows actual aircraft position in relation to this selected course.

### COURSE DEVIATION DOTS

In VOR operation, each dot represents 5 degrees deviation from centerline (75 microamperes). In ILS operation, each dot represents 1 degree deviation from centerline (also 75 microamperes).

### TO-FROM POINTER

Two flags, 180 degrees apart. One always points the direction TO the station along the selected VOR radial.

### GLIDE SLOPE POINTER

Displays glide slope deviation. Pointer is in view only when tuned to a localizer frequency. Aircraft is below glide path if pointer is displaced upward, and each dot represents 75 microamperes or approximately 0.4 degree displacement.

### COMPASS SYNCHRONIZATION ANNUNCIATOR

Consists of the ● or X (dot or cross) symbol displayed in a window. When the compass system is in the slaved mode, the display will oscillate between the ● and X, indicating the heading dial is synchronized with gyro-stabilized magnetic heading.

### SLAVE-FREE SWITCH

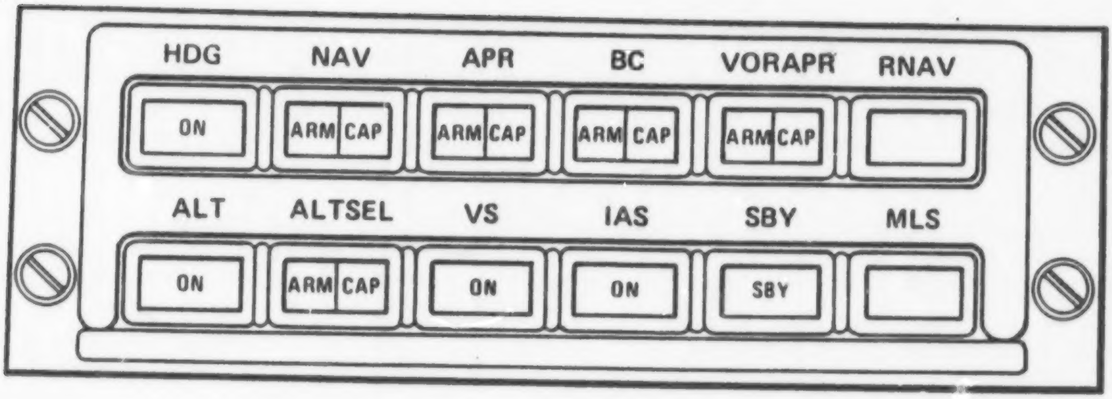
This remotely located switch is used to select either the slaved or free gyro mode of operation.

### SET HDG SWITCH

If needed during compass initialization, this remotely located switch manually positions the heading dial for compass synchronization in the slave mode; and gyro updating in the free mode.

Figure 9 Cont'd

**Figure 10**
**Flight Director Mode Selector**


HDG
NAV
APR
BC
VORAPR
RNAV
ON
ARM CAP
ARM CAP
ARM CAP
ARM CAP
ALT
ALTSEL
VS
IAS
SBY
MLS
ON
ARM CAP
ON
ON
SBY

FLIGHT DIRECTOR MODE SELECTOR

Figure 10 Cont'd

# Controls

## FLIGHT DIRECTOR MODE SELECTOR

The Flight Director Mode Selector provides all flight director mode selection (except that which is initiated by throttle-mounted switches).

### HEADING SELECT MODE (HDG)

The heading select mode is selected by pressing the HDG button on the Mode Selector. The HDG annunciator illuminates. In the HDG mode, the flight director computer provides inputs to the roll command bar to command a turn to the heading indicated by the heading bug on the HSI. The heading select signal is gain programmed as a function of airspeed. When HDG is selected, it overrides the NAV, APR, BC, and VORAPR modes. In the event of a loss of valid from the VG or compass, the roll command bar is biased out of view.

### NAVIGATION MODE (NAV)

The navigation mode represents a family of modes for various navigation systems including VOR, localizer, and RNAV.

### VOR MODE (NAV)

The VOR mode is selected by pressing the NAV button on the Mode Selector with the navigation receiver tuned to a VOR frequency. When outside the lateral beam sensor trip point, the roll command bar receives a heading select command as described above and the HDG mode annunciator on the Mode Selector is illuminated along with the NAV ARM annunciator on the Mode Selector. Upon reaching the lateral beam sensor trip point, the system automatically switches to the VOR mode—HDG and NAV ARM annunciators extinguish and the NAV CAP annunciator on the Mode Selector will illuminate. At capture, a command is generated to capture and track the VOR beam. VOR deviation is gain programmed as a function of distance from the station. This programming corrects for the beam convergence, thus optimizing the gain through the useful VOR range. To utilize this feature, the DME must be tuned to the same VOR station as the NAV receiver which is feeding the flight director. The course error signal is gain programmed as a function of airspeed. Crosswind washout is included which maintains the aircraft on beam center in the presence of crosswind. The intercept angle and DME distance are used in determining the lateral beam sensor trip point to ensure smooth and comfortable performance during bracketing.

When passing over the station, an overstation sensor detects station passage removing the VOR deviation signal from the command until it is no longer erratic. While over the station, course changes are made by selecting a new course on the HSI.

If the NAV receiver is not valid prior to the capture point, the lateral beam sensor will not trip and the system will remain in the HDG mode. After capture, if the NAV receiver, compass data, or vertical gyro goes invalid, the roll command bar will bias out of view. The NAV CAP annunciator on the Mode Selector will extinguish if the NAV receiver becomes invalid and remain off until the receiver again becomes valid.

### VOR APPROACH MODE (VORAPR)

The VOR approach mode is selected by pressing the VORAPR button on the Mode Selector with the navigation receiver tuned to a VOR frequency. The mode operates identically to the VOR mode with the gains optimized for a VOR approach.

### RNAV MODES (RNAV, RNAV APPROACH, NAV)

The RNAV and RNAV approach modes are selected by pressing the NAV button (NAV CAP occurs at selection) with the RNAV button ON and RNAV information being supplied to the system. Operation is similar to the VOR and VOR approach modes with separate gains provided to optimize for the RNAV input.

### LOCALIZER MODE (NAV)

The localizer mode is selected by pressing the NAV button on the Mode Selector with the navigation receiver being tuned to a LOC frequency. Mode selection and annunciation in the LOC mode is similar to the VOR mode. The localizer deviation signal is gain programmed as a function of radio altitude, time, and airspeed. If the radio altimeter is invalid, gain programming is a function of glide slope capture, time, and airspeed. Other valid logic is the same as the VOR mode. This mode is used when there is no valid glide slope information available, as glide slope capture is locked out.

### BACK COURSE MODE (BC)

The back course mode is selected by pressing the BC button on the Mode Selector. Back course operates the same as the LOC mode but with the deviation and course input signals to the flight director reversed to make a back-course approach on the localizer. Glide slope capture is locked out when in the BC mode. When BC is selected and outside the lateral beam sensor trip point, BC ARM and HDG will be annunciated on the Mode Selector. At the capture point, BC CAP will be annunciated with BC ARM and HDG extinguished.

### APPROACH MODE (NAV, APR)

The approach mode is used to make an ILS approach. Pressing the APR button with a LOC frequency tuned arms both the localizer and glide slope modes. When the APR button is pressed and the above conditions are met, both the NAV and APR modes are armed to capture the localizer and glide slope, respectively. Operation of the LOC mode is the same as described above. With the APR mode armed, the pitch axis can be in any one of the other pitch modes except go-around. When reaching the vertical beam sensor trip point, the system automatically switches to the glide slope

Ground mapping operations require the "MAP" pushbutton to be engaged to disable the STC circuitry. The 10 NM range selected and "gain preset" is set for optimum detection. The antenna is tilted downward until the desired amount of terrain is obtained. A 2.5° tilt was optimum for ground mapping on the Pemberton approach procedure.

### 7.2.3 Flight Data Recorder System

The Flight Data Recorder System was used to collect data during the flight tests. The system is manufactured by Teledyne/Sunstrand, and is installed by deHavilland in the DHC-7. It is designed to assess, measure, and record critical parameters of flight for subsequent analysis or investigations of incidents or accidents.

The system comprises a crash-protected data tape recorder, an underwater locator beacon, a data acquisition unit, a three-axis accelerometer, and an acceleration switch. The system is energized when the anti-collision lights are on and power is applied to the AC bus system. The system is turned off automatically when the anti-collision lights are turned off, and the aircraft wheels are on the ground.

The system operates from a power supply of 115V, 400 Hz, which is applied directly to the data acquisition unit, and to the recorder. Provided the AC system is on, power will be applied and the system will commence recording.

The Digital Flight Data Recorder (DFDR) is a crash protected digital device which accepts input data in serial binary form from the data acquisition unit. The data is stored on a reel of metal tape to provide a crash-survivable record of critical flight parameters for the previous 25 hours. Contained in an environmentally protected enclosure, the recorder is located in the tail cone of the aircraft, where the probability of crash damage is minimized.

The Flight Data Acquisition Unit (FDAU) assesses a minimum of thirty channels of analog data from different aircraft instruments and flight parameter measurement transmitters, and converts the data to a sequential or serial type of binary digital information, suitable for application to the data recorder. The acquisition unit contains an analog input section, an analog-to-digital converter, a digital output section, and a power supply section. The analog section acquires, preconditions, and multiplexes the data from the aircraft transmitters. The a-to-d converter translates the analog voltages into digital form prior to application to the digital section. The digital section then generates the addresses which control input and output multiplexing, and provides digital interfaces for asynchronous inputs, delivery output data to the DFDR. The power supply section provides all internal operating voltages, self-test reference voltages, and excitation voltages which are multiplexed out to certain measurement transmitters. The FDAU is also located in the aircraft's tail cone.

Table E, overleaf, lists the channel and parameters being recorded. Parameters can be measured up to four times a second.

Discussions with Teledyne Controls revealed that the FDAU 70-201 could be modified to accept up to 50 measured parameters. Teledyne provided information to make the modifications. The following additional parameters were collected by the FDAU during the flight demonstration tests:

DME #1 (miles)
DME #2 (miles)
Loran C (track)
MLS #1 ON
MLS #2 ON
AZ #1
AZ #2

GS #1
GS #2
BAZ #1 SLT (select)
BAZ #2 SLT
BAZ #1 VLD (valid)
BAZ #2 VLD

Canadian Airlines International agreed to write the special software needed to determine the measurement ranges to be recorded for each of the additional parameters. AirBC Avionics determined the measured ranges by change in voltage transmitted from each of the devices to be measured. AirBC also made the necessary changes to the FDAU to record the additional parameters. An example of the FDAU collected data is shown in Figure 11.

### 7.2.4 MLS Receivers

The MLS airborne equipment installed on C-GXPO is a dual Bendix-King MLS 21A system. Each system consists of an ML 211B receiver, two AT 213A fore and aft antennae, and a CD 212B Control Display. The MLS 21 provides both analog and digital (ARINC 429) outputs, making it compatible with electro-mechanical flight instruments as it is with Electronic Flight Information Systems (EFIS), if installed. The unit is designed to accommodate Category III autoland operations in the future. The following presents the MLS 21 operational specifications:

## Table E
## FLIGHT DATA ACQUISITION UNIT PARAMETERS

| Channel | Parameter |
|---|---|
| 1 | Time (not GMT) |
| 2 | Altitude (Hp) |
| 3 | Airspeed |
| 4 | Vertical Acceleration |
| 5 | Heading |
| 6 | Lateral Acceleration |
| 7 | Pitch Altitude |
| 8 | Roll Attitude |
| 9 | Pitch Trim Position |
| 10 | Pitch (Left elevator surface position) |
| 11 | Lateral control (spoiler LH inbd.) |
| 12 | Lateral Control (spoiler RH inbd.) |
| 13 | Yaw Control (Rud Surf.) |
| 14 | Prop RPM Eng. 1 |
| 15 | Prop RPM Eng. 2 |
| 16 | Prop RPM Eng. 3 |
| 17 | Prop RPM Eng. 4 |
| 18 | Gas Gen RPM Eng. 1 |
| 19 | Gas Gen RPM Eng. 2 |
| 20 | Gas Gen RPM Eng. 3 |
| 21 | Gas Gen RPM Eng. 4 |
| 22 | Torque Eng. 1 |
| 23 | Torque Eng. 2 |
| 24 | Torque Eng. 3 |
| 25 | Torque Eng. 4 |
| 26 | Outside Air Temp. |
| 27 | Flap Position |
| 28 | Transmitter Keying (IHF Comm 1 & 2) |
| 29 | Autopilot Engage/ Disengage |
| 30 | Weight Switch |

## Figure 11
## Example of FDAU Collection Data

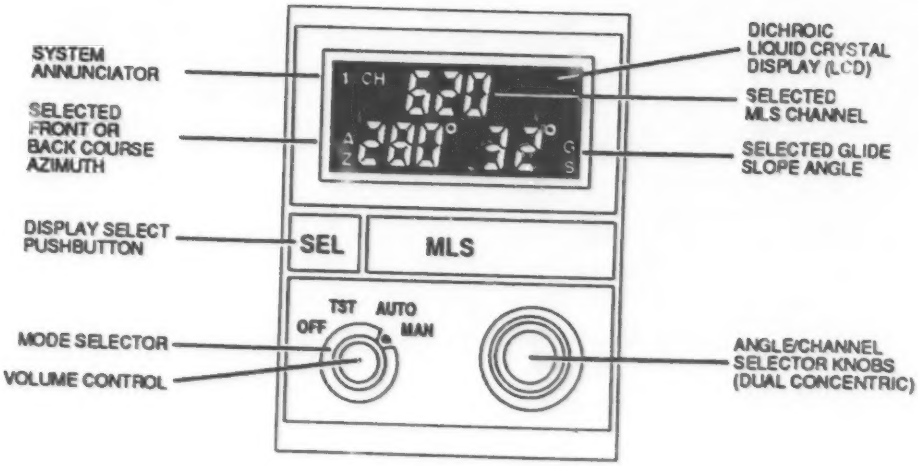
```
                                             AIRBC XPO MLS TEST JULY 1987

     TRIP      DATE          LEG     GWT      CAPT      F/O     FUEL     C/G
      0         0             0       0         0        0        0       0         0          0

ACT    REL              ALT     CORR    IAS     MAG     MLS     MLS     MLS     MLS    DME    DME     1 2 3 4 5 6 7 8 9 10
FRAME  FRAME  GMT       FT       ALT   KNTS    HEAD    AZ#1    AZ#2    GS#1    GS#2   #1     #2

 2989   2989    0    2502.   1574.   90.1   115.9     1.4    -3.1    -9.6    -9.0   2.14   2.26    1 1 1 1 0 0 1 1 0 0
                     2495.   1567.   89.2   115.9    -2.0    -6.1    -6.4    -7.0   2.14   2.20    1 1 1 1 0 0 1 1 0 0
                     2481.   1552.   89.9   115.9    -5.9    -6.6    -6.4    -4.5   2.14   2.17    1 1 1 1 0 0 1 1 0 0
                     2467.   1538.   90.5   115.9    -5.9   -10.7    -4.9    -4.9   2.14   2.14    1 1 1 1 0 0 1 1 0 0
 2990   2990    0    2453.   1524.   91.0   115.6   -10.2   -14.8    -3.3    -3.5   2.11   2.11    1 1 1 1 0 0 1 1 0 0
                     2432.   1503.   91.4   115.3   -14.3   -15.8    -2.5     0.8   2.04   2.08    1 1 1 1 0 0 1 1 0 0
                     2417.   1488.   91.7   115.3   -16.6   -20.5     2.9     2.9   1.98   2.08    1 1 1 1 0 0 1 1 0 0
                     2403.   1474.   91.5   115.6   -19.1   -22.9     5.3     5.3   1.95   2.04    1 1 1 1 0 0 1 1 0 0
 2991   2991    0    2389.   1460.   92.0   116.2   -21.5   -23.4     5.3     8.2   1.92   2.01    1 1 1 1 0 0 1 1 0 0
                     2375.   1445.   92.7   117.4   -23.6   -25.4    10.0    11.9   1.89   1.98    1 1 1 1 0 0 1 1 0 0
                     2361.   1431.   93.2   119.5   -23.0   -25.6    12.3    12.5   1.86   1.95    1 1 1 1 0 0 1 1 0 0
                     2347.   1417.   93.5   121.6   -21.3   -20.1    14.6    15.8   1.83   1.95    1 1 1 1 0 0 1 1 0 0
 2992   2992    0    2325.   1396.   94.3   123.8   -19.7   -17.6    17.8    17.8   1.86   1.89    1 1 1 1 0 0 1 1 0 0
                     2311.   1381.   95.2   125.5   -14.5   -14.3    17.0    18.6   1.80   1.86    1 1 1 1 0 0 1 1 0 0
                     2297.   1367.   95.5   127.0    -8.4    -9.6    20.1    20.1   1.77   1.83    1 1 1 1 0 0 1 1 0 0
                     2283.   1353.   96.6   127.3    -5.7    -3.9    23.2    23.2   1.74   1.83    1 1 1 1 0 0 1 1 0 0
 2993   2993    0    2254.   1324.   96.3   127.0     0.0     0.0    23.2    21.1   1.74   1.80    1 1 1 1 0 0 1 1 0 0
                     2219.   1289.   95.0   126.7     2.9     5.5    20.9    19.3   1.71   1.77    1 1 1 1 0 0 1 1 0 0
                     2198.   1267.   95.7   126.4     9.2    11.7    22.5    22.3   1.65   1.74    1 1 1 1 0 0 1 1 0 0
                     2169.   1239.   95.0   126.1    17.4    17.2    20.1    19.1   1.65   1.71    1 1 1 1 0 0 1 1 0 0
 2994   2994    0    2148.   1217.   94.8   125.5    18.9    20.3    20.1    17.4   1.62   1.68    1 1 1 1 0 0 1 1 0 0
                     2120.   1189.   94.6   124.9    23.2    25.2    17.0    17.2   1.59   1.68    1 1 1 1 0 0 1 1 0 0
                     2091.   1160.   94.1   124.0    28.1    28.5    17.0    15.4   1.59   1.65    1 1 1 1 0 0 1 1 0 0
                     2063.   1132.   93.9   123.4    32.4    34.4    14.6    15.4   1.53   1.59    1 1 1 1 0 0 1 1 0 0
 2995   2995    0    2042.   1110.   94.1   122.8    37.9    38.5    13.9    12.3   1.53   1.56    1 1 1 1 0 0 1 1 0 0
                     2013.   1082.   94.5   122.5    40.4    39.3    10.7     9.4   1.50   1.59    1 1 1 1 0 0 1 1 0 0
                     1992.   1060.   94.7   122.2    41.4    40.8    10.0     9.0   1.43   1.53    1 1 1 1 0 0 1 1 0 0
                     1964.   1032.   93.2   121.6    43.6    43.8     8.4     6.8   1.43   1.50    1 1 1 1 0 0 1 1 0 0
 2996   2996    0    1943.   1011.   92.5   121.0    46.1    45.9     9.2     7.0   1.40   1.46    1 1 1 1 0 0 1 1 0 0
                     1921.    989.   92.2   120.1    48.4    47.3     8.4     6.4   1.40   1.46    1 1 1 1 0 0 1 1 0 0
                     1893.    961.   92.2   119.2    48.8    48.2     7.6     6.1   1.37   1.43    1 1 1 1 0 0 1 1 0 0
                     1872.    939.   92.3   118.6    48.8    47.1     4.5     3.7   1.34   1.40    1 1 1 1 0 0 1 1 0 0
 2997   2997    0    1843.    911.   91.9   117.7    48.0    45.9     2.9     3.3   1.37   1.40    1 1 1 1 0 0 1 1 0 0
                     1822.    889.   90.4   116.8    44.7    41.6     3.7     2.9   1.31   1.37    1 1 1 1 0 0 1 1 0 0
                     1801.    868.   90.3   115.3    41.6    38.3     3.7     2.1   1.31   1.34    1 1 1 1 0 0 1 1 0 0
                     1787.    854.   90.9   114.7    37.7    32.8     3.7     3.1   1.28   1.31    1 1 1 1 0 0 1 1 0 0
 2998   2998    0    1758.    825.   91.0   114.4    31.6    26.4     0.6     1.6   1.25   1.25    1 1 1 1 0 0 1 1 0 0
                     1737.    804.   89.0   114.1    27.0    20.9     0.6    -1.4   1.19   1.25    1 1 1 1 0 0 1 1 0 0
                     1709.    775.   91.3   114.1    18.9    14.5    -1.0    -3.9   1.13   1.22    1 1 1 1 0 0 1 1 0 0
                     1687.    754.   90.4   114.1     9.8     6.6    -4.9    -6.4   1.10   1.19    1 1 1 1 0 0 1 1 0 0
 2999   2999    0    1659.    725.   89.4   114.4     4.1    -0.8    -8.8   -10.5   1.10   1.19    1 1 1 1 0 0 1 1 0 0
                     1631.    697.   88.5   115.6    -2.7    -4.1   -12.7   -15.0   1.07   1.16    1 1 1 1 0 0 1 1 0 0
                     1602.    668.   90.3   117.1    -5.3    -8.2   -16.6   -18.4   1.04   1.13    1 1 1 1 0 0 1 1 0 0
                     1588.    654.   91.0   119.2    -6.8    -9.2   -17.4   -17.6   1.01   1.07    1 1 1 1 0 0 1 1 0 0
 3000   3000    0    1567.    633.   91.4   121.0    -4.3    -8.8   -16.6   -15.4   0.98   1.04    1 1 1 1 0 0 1 1 0 0
                     1553.    618.   91.1   121.9    -4.5    -5.9   -12.7   -10.0   0.95   1.01    1 1 1 1 0 0 1 1 0 0
                     1546.    611.   92.3   122.2    -2.0    -2.9    -4.9     2.3   0.95   1.01    1 1 1 1 0 0 1 1 0 0
                     1539.    604.   92.4   121.9    -1.4    -2.1    10.0    17.8   0.92   0.98    1 1 1 1 0 0 1 1 0 0
```

| | |
|---|---|
| Functions Displayed | AZ, BAZ, EL (GS), HAZ (AZ) |
| AZ/BAZ Accuracy | +/- 0.017° Digital |
| EL Accuracy | +/- 0.015° Digital |
| AZ Angular Range | - 60° to + 60° |
| BAZ Angular Range | - 40° to + 40° |
| EL Angular Range | + 2° to 19.9° |
| AZ/BAZ Switching | Remote Switch |
| Acquisition Time | 1.0 second, nominal |

- ML-211B MLS Angle Receiver - is a lightweight unit (7.8 lbs.) consisting of a Radio Frequency (RF) module, processor board, multifunction board, power supply, interface module, and master interconnect board. The RF module contains a C-band assembly, Intermediate Frequency (IF) module, BITE module, synthesizer control module, VCO (800.65 to 810.60 Hz), and a front-end bias module that includes the antenna switch driver. The power supply is centrally located within the receiver unit. It operates from the 28 Vdc input. The unit connector which provides the interface to the control display and aircraft wiring is located in the rear panel of the unit. The front panel consists of two RF connectors which are linked, through low-loss coaxial cables, to the forward and aft antennae in the system. The integral antenna switch circuit allows the receiver to automatically select the antenna receiving the strongest signal or allows the forward antenna to be selected using a discrete input. The master interconnect board, located behind the rear panel, provides power and signal distribution within the unit via ribbon cables with connectors.

- CD-212B MLS Control Display - includes an interface board, dichroic display module, and switches. The interface board contains an electronic buffer to isolate the dichroic display from the external environment. The dichroic display contains a high contrast ratio display, display drivers, integral heater and temperature controller, and an incandescent lighting module. The function selector, the display select pushbutton and the angle/channel selector are mounted on the front panel and connected to the interface board through a flexible pointed interconnect. The dichroic readout displays the selected MLS channel, azimuth, and glideslope angle. Figure 12 shows the CD 212B Control Display.

Figure 12
CD 212B Control Display


SYSTEM ANNUNCIATOR
SELECTED FRONT OR BACK COURSE AZIMUTH
DISPLAY SELECT PUSHBUTTON
MODE SELECTOR
VOLUME CONTROL
DICHROIC LIQUID CRYSTAL DISPLAY (LCD)
SELECTED MLS CHANNEL
SELECTED GLIDE SLOPE ANGLE
ANGLE/CHANNEL SELECTOR KNOBS (DUAL CONCENTRIC)
1 CH
620
AZ
280°
3.2°
GS
SEL
MLS
OFF
TST
AUTO
MAN

CD 212B

> AT 213A Antenna - are vertically polarized antenna allowing connection of forward and aft antenna to the receiver C-band inputs. In operation, the receiver selects the antenna receiving the strongest signal. The antenna connector is an N type.

### 7.2.4.1 MLS Receiver Operation

Azimuth and elevation deviation information is displayed to the pilot via the Flight Control System instrument indicators. The indicators display the difference between the actual approach angles and the angles selected on the control display. The control display allows selection of the channel, azimuth angle, and glideslope angle, as well as volume control adjustment for the morse code signal transmitted to identify the ground facility. The ML-211B MLS Angle Receiver processes the C-band signals generated by the ground stations to provide digital and analog angular data. The digital angular data output of the receiver is transmitted in the ARINC 429 format. It is applied to the Flight Control System and to the azimuth and glideslope readout displays. The analog angular data is supplied to the deviation indicator which displays the differences between the aircraft position relative to the azimuth angle selected on the control display and the aircraft elevation angle relative to the selected glideslope.

The aircraft antennae receive the C-band signals radiated by the ground stations. The receiver selects the antenna receiving the strongest signal (or can be forced with an internal input to select the forward antenna). The RF circuit provides front end gain, wide band filtering, and mixing to produce log video and limited video outputs. The video is demodulated using a phase-locked loop, and the demodulated DPSK is applied directly to the LSI. A portion of the LSI circuit decodes the DPSK, and starts a real-time counter if an azimuth, high-rate azimuth, back azimuth, or elevation preamble is present. The log video output is an envelope detected signal containing the beam information. All amplitude samples of the converted log video are stored in the main processor memory.

The multifunction processor computes the selected azimuth, glideslope, and channel information received from the control display. It formats the data and sends it back to the control display, and to the main processor. It generates a test signal and monitors test inputs from all modules. Standard and high level deviation signals and their associated flags are supplied to an indicator to position the deviation pointer and activate warning flags when necessary.

### 7.2.4.2 MLS Engineering and Equipment Installation

As indicated in a earlier chapter, deHavilland had developed engineering drawings for an MLS installation on a demonstration DHC-7. The AirBC MLS requirements were sufficiently different to have its own design and engineering, using the deHavilland installation as a guide. AirBC Avionics coordinated the engineering and installation. Pacific Avionics and Instruments Ltd. were contracted to develop the necessary drawings for Transport Canada certification and to install the MLS receivers. Bendix-King provided advice during the MLS receivers' installation. Specifically, Pacific Avionics were contracted to provide the following:

- Preparation of installation drawings and blue prints to a format suitable to Transport Canada and AirBC, with reference to existing aircraft drawings and using standard DHC-7 (chapter 34) ATA-100 wiring codes.
- To construct installation wiring harnesses.
- To install wiring harnesses and to modify existing aircraft system wiring to accommodate the MLS installation.
- To install MLS receivers, control units, antennae, connector kits, terminal blocks, mounting trays, and supplemental parts.
- To provide on-going installation support for a period of 6 months following completion.

The contractor was required to incorporate the following system features into the MLS installation:

- Satisfactory means of switching conventional ILS deviation and flag information for MLS azimuth, elevation, and flag information in an "ILS look-alike" fashion.
- A suitable relay switching arrangement capable of substituting MLS for ILS data to the aircraft flight director and HSI systems when MLS mode is selected.
- Dual systems totally independent of each other, connected to existing aircraft bus, instrumentation, and audio systems.

- Incorporation of MLS mode annunciation and switching panel into the aircraft flight instrument panels. Lighted push switches of a standard type to be used on the annunciator control panel.

- Annunciator lamp power sources connected to existing aircraft 28V advisory lighting systems incorporating existing dimming and test features.

- Annunciation to provide the following indications:

  : both AZ/EL and BAZ signals are being received and are valid prior to selecting MLS information to the flight instrument systems.

  : indication that the CDI and HSI are selected to MLS.

  : indication that AZ/EL and BAZ signals are valid when flight instruments are selected to AZ/EL or BAZ modes.

  : indication that all relays have in fact switched when MLS is selected.

  : indication that DME is automatically tuned to the MLS paired channel when MLS is selected.

- Manual activation of BAZ through the existing power lever "go-around" button.

- Existing flight director function to be maintained in the selection of BAZ.

- BAZ mode to have glideslope flags in view and glideslope deviation pointers biased out of view.

- Any MLS mode not to affect the existing conventional NAV ILS-VOR system when MLS not selected to flight instruments.

- DME automatically timed to MLS paired frequency when MLS selected to flight instruments.

- A/P system disabled when MLS selected to flight instruments.

### 7.2.4.3 Control Annunciator

As noted in the previous sub-section, an MLS control annunciator was designed for the MLS installation. Several designs were developed and modifications were made to the designs based on experience gained during the flight demonstration tests. Most of the changes related to the push button switches, identification lettering on the switches, and the illumination of the annunciator switches. Figure 13, overleaf, illustrates the control annunciator design. The annunciator was mounted on the centre instrument panel in a location to be readily monitored by both flight crew.

The switch-light arrangement on the control annunciator is a key factor in the certification process and a description of the switch-light functions follows:

: DS-1 "MLS Coverage Area" - illuminated green if MLS receiver is processing a valid MLS signal in AZ or BAZ coverage area.

: DS-2 "Back Azimuth Available" - illuminated blue provided MLS receiver is detecting BAZ available bit on the data word in both AZ and BAZ coverage area.

: DS-3 "Back Azimuth Coverage" - illuminated blue if MLS receiver is processing a valid BAZ signal while in BAZ coverage area only.

:S-1 "MLS Nav Select" - illuminated white when de-activated provided MLS receiver is energized. Illuminated green when S-1 is activated. Activation possible only when MLS receiver energized first. Push on/push off switch energizes MLS - VOR/LOC transfer relay to connect MLS navigation signals to flight instruments. White light provided for day or night illumination.

: DS-4 "Azimuth Select" - illuminates green during initialization of MLS receiver at power up or when receiver is manually selected to AZ mode by pressing AZ/BAZ select switch on control yoke to AZ position.

: DS-5 "Back Azimuth Select" - illuminates blue when MLS receiver is manually selected to BAZ mode by pressing AZ/BAZ select switch on control yoke to BAZ position.[1]

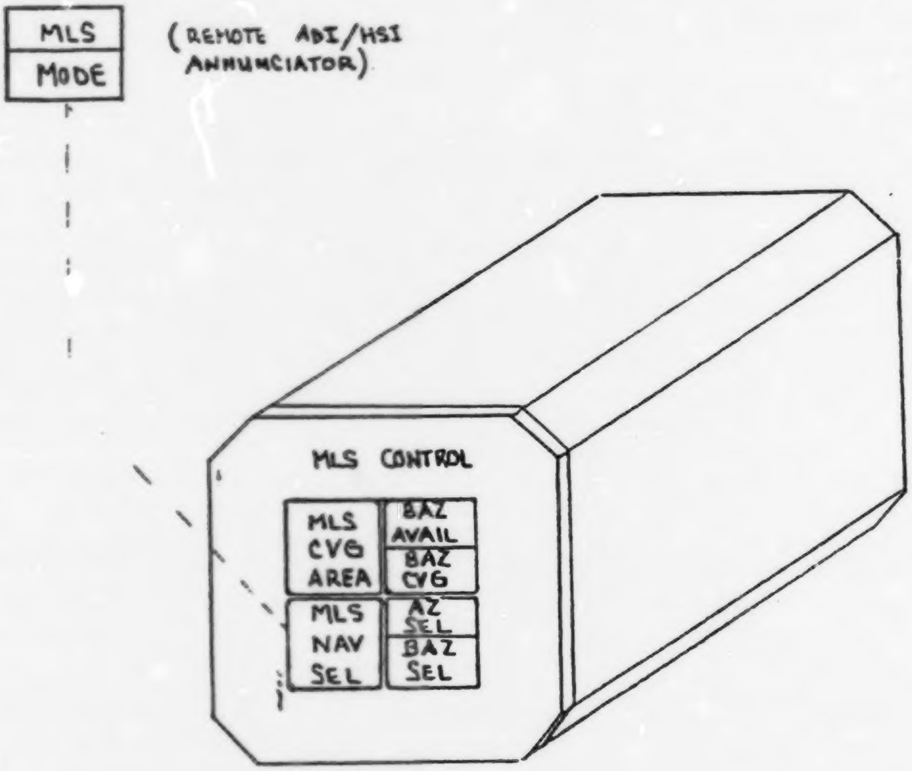
---

[1] A review of the switching capability of the AZ/BAZ select light is being undertaken. This review may conclude that a back-up means of switching is advisable in the event of

Figure 13
MLS Control Annunciator Design

MLS CONTROL ANNUNCIATOR - DHC-7

REVISION III
OCTOBER/87


MLS
MODE
(REMOTE ADI/HSI ANNUNCIATOR)
MLS CONTROL
MLS CVG AREA
BAZ AVAIL
BAZ CVG
MLS NAV SEL
AZ SEL
BAZ SEL

: DS "MLS Mode" (remote annunciator) - illuminates white when MLS -VOR/LOC relay is energized to the MLS position following activation of the "MLS Nav Select" button, S-1. This is verification that the relay has switched to MLS mode.

### 7.2.5 Loran C

For the purpose of the MLS/STOL demonstration flights, a Loran C receiver was installed in C-GXPO. The Loran C navigation system provides an independent navigation reference which can be used to confirm the accuracy of the ground based MLS system.

Loran is a pulse-type radio navigation system consisting of a receiver and several ground transmitters. The receiver precisely measures the latitude and longitude position of the aircraft when signals are received from the ground station. The time when a signal arrives at the receiver from a single station is the time of arrival (TOA). The receiver can compute the time difference (TD) between the time of arrival of two signals from two ground stations. Using the time difference, and the geographic locations of the two ground stations, a curved line on the earth's surface can be defined on which an aircraft must lie. This line is the line of position (LOP). Computing two lines of position from two station pairs determines a single position on the earth's surface where the aircraft is located (eg. intersect of two LOP's).

Loran ground stations are grouped into chains with each chain consisting of a single master station, and two to four secondary stations. Typically, stations are positioned several hundred miles apart. Each secondary station sends out its radio pulses at precise time delays after the master sends out its radio pulses. Based on the known delay, the receiver establishes an LOP for each master-secondary pair. Using any two secondaries and the master, the fix of the aircraft position is determined. All stations transmit on a frequency of 100 KHz. Each chain is assigned a unique Group Repetition Interval (GRI) to distinguish a chain from other chains. The four digit GRI represents the time interval between transmissions of a complete series of pulses.

---

a control yoke selector switch failure.

The Canadian West Coast chain provides signal coverage in the Pemberton area. The GRI of the chain is 5990. The master station (M) is Williams Lake, B.C. Secondary stations include Shoal Cove, AK (X), George, WA. (Y), and Port Hardy B.C. (Z).

In terms of Loran accuracy, the FAA Advisory Circular 90-45A sets out RNAV error criteria as follows:

| Flight Segment | Enroute | Terminal | Approach |
|---|---|---|---|
| Along Track Error (ATE) | 1.5 NM | 1.1 NM | 0.3 NM |
| Cross Track Error (CTE) | 2.5 NM | 1.5 NM | 0.6 NM |
| Flight Tech. Error (FTE) | 2.0 NM | 1.0 NM | 0.5 NM |

Flight tests of Loran C were conducted in the State of Vermont in 1981 by the U.S. Department of Transportation, the National Aeronautics and Space Administration (NASA), and the State of Vermont. Measured performance during the flight tests was shown to exceed the minimum accuracy requirements specified for area navigation for all phases of flight. Enroute operations were within +- 0.73 NM of the desired track compared with the requirement of +- 2.5 NM. Terminal operations were within +- 0.60 NM of the desired track compared to +- 1.5 NM requirement. Non-precision final approach operations were +- 0.32 NM, compared to the minimum requirement of +- 0.6 NM for all approach operations.

### 7.2.5.1 ANI 7000 Loran C

Advanced Navigation Inc., a Frederick, Maryland manufacturer of Loran C receivers, loaned AirBC an ANI 7000 Loran C for the MLS/STOL flight demonstration tests. The ANI 7000 system consists of the following components:

- > Receiver Computer Unit (RCU) - contains the RF amplifier and navigation computer (remotely mounted).
- > Central Display Unit (CDU) - user interface with the system. It provides the central/display interface to the RCU (mounted in aircraft cockpit).
- > Antenna/Antenna Coupler - an E-field type antenna with an internal coupler contained in the base of the antenna.

> Course Deviation Indicator (CDI) - panel mounted instrument that provides an indication of whether the aircraft is left or right of a desired track.

The ANI 7000 has the following features:

> Simultaneous tracking of up to eight stations on four chains.

> Non-volatile storage of up to 200 waypoints and 99 routes.

> Automatic Loran chain/station selection and de-selection.

> Waypoint definition by latitude/longitude, offset, time difference, or present position.

> Display of position, groundspeed, and groundtrack with or without using waypoints.

> Display of distance, bearing, and estimated time enroute to waypoint.

> Display of desired back and cross track error for flight legs.

> Automatic or manual route leg sequencing.

> Capability to compute flight leg data without disturbing ongoing navigation.

AirBC Avionics, with the assistance of ANI, installed the ANI 7000 in C-GXPO. The RCU was located in the standard avionics rack. The CDU was installed in the cockpit, replacing the right RNAV unit on the control pedestal. The antenna was installed under the aircraft hull, using a standard antenna blank plate location on the aircraft. The antenna installation did not require cutting the pressured hull of the aircraft. Due to possible electrical ground interference, the under-hull location was not the best location for the antenna. Coaxial cable and standard connectors linked the antenna to the RCU and CDU components. A course deviation indicator was installed on the lower left instrument panel, and connected to the RCU.

### 7.2.6 Video Cameras

A video record of the MLS/STOL flight demonstrations was made to illustrate flight instrument data and other flight test information. These video records were later correlated with the Flight Data Acquisition Unit recorded data to examine in more depth any areas of concern which may have occurred during the tests. The recorded videos also were available to Transport Canada for certification purposes.

Three standard JVC VHS format video cameras were temporarily mounted in the aircraft cockpit. AirBC Avionics constructed portable mounting brackets for each video camera, as well as a special chassis to house the video recorders, power supply, recording synchronization, cables and cable connectors. One video camera was mounted on the left side console, directed at the left hand instrument panel. A second video camera was located on the right side console for the right instrument panel. The third video camera was mounted above the crew door access. This camera could be directed down to the control pedestal to monitor the MLS Control Display/Control Annunciator, Loran C CDU, and throttle settings. It could also be rotated up to be directed to the cockpit windshield for exterior scenes of passing terrain. Audio connections were also made in conjunction with the video to simultaneously record on the video recorders, events taking place during the flight demonstration tests. These audio recordings described flight test information, as well as providing a reference on the video as to the test being performed, and the location of the aircraft during the test.

The video recorder chassis was located in the main cabin of the aircraft. The video output could be observed by the technician during the flight to assure proper focus of the video cameras and the timed synchronization of the various recordings was operating.

Cam video cameras were not used due to synchronization difficulties, as well as the lack of ability to change focal length during flight. Beta format was considered for its higher camera resolution, and should be considered in any future tests. Difficulty was experienced in keeping the video cameras in focus, due to aircraft vibration and the short focal length of the standard video camera. During the flight demonstration, it was difficult for the flight crew to make focal adjustments in conjunction with the technician in the aircraft cabin, and carry out flight duties at the same time. Technicians could not make the adjustments due to the location of the video cameras in the cockpit.

### 7.2.7 Storage Oscilloscope

During the MLS/STOL flight tests, particularly those later tests associated with the BAZ signals, additional information was needed on the MLS signal being received, using the log video output features of the MLS-21A to analyze the signal.

A Tektronix portable storage oscilloscope was acquired for the purpose of evaluating the MLS signal. The storage oscilloscope allows the digitizing, viewing, and storage of high bandwidth and complex signals such as an MLS signal. The digitizing consists of sampling the value of input signal at discrete points in time, and quantizing the value into a binary number by the analog-to-digital converter. The sample rate is determined by the time base. Stored data can be read and reconstructed for display or further waveform processing.

The storage oscilloscope was interfaced to the Bendix-King ML-211B MLS Angle Receiver, using the Master interconnect board. The power source used is a 115V inverter, the same power source used for the video cameras located in the aircraft cabin.

In later flight tests, Transport Canada supplied a Tektronix storage oscilloscope with a coupled digital video camera system. This allowed the MLS signals to be recorded and viewed at a later time on a high resolution television monitor.

### 7.2.8 Air/Ground Communication

Most of the air/ground communication was accomplished using the aircraft VHF radio communication frequencies, to communicate to ground personnel during the tests. Portable hand-held VHF transceivers were used by ground personnel. In certain flight tests, particularly MLS approach and departure accuracy tests, portable hand-held FM transceivers were used, both in the aircraft and on the ground to communicate with the ground survey/video camera crew.

It became apparent during the MLS/STOL flight tests that portable radio receivers, with standby batteries, were essential, particularly when modifications were being made to the AZ/EL and BAZ sites during the flight tests, and the up-to-date status of the changes were required by the flight crew and onboard technicians.

## 7.3 Ground Equipment

Research ground equipment was used during the MLS/STOL flight tests. The ground equipment is described in the following paragraphs.

### 7.3.1 Loran C Monitors

Loran C monitoring equipment was installed at the Pemberton Airport to determine Loran C signal coverage and signal quality in the area. Two separate monitors were used, each providing a cross check on the accuracy of the Loran C signal being received.

The U.S. Coast Guard, who operate and maintain the U.S. Loran C stations, provided a Loran C monitor for the duration of the project. Coast Guard personnel installed the Loran C antenna, ground wires, and cables to the monitor. The core component of the monitor is an LC-1200 receiver, which is capable of tracking a Master and four Secondaries on each of two chains.

A second Loran C monitor unit was provided by Megapulse/Racal, who are the sole manufacturers of Loran C transmitter stations. Megapulse personnel installed the monitor system, including the antenna/ ground system at the Pemberton Airport. An Accufix 500 receiver is used in the monitor.

The two ground-based signal monitoring stations provided a data base of Loran C signals in the inland and mountainous area of the Pemberton Valley. The monitoring equipment allowed the evaluation of Loran C signals in the electromagnetic noise and interference environment of the Pemberton Airport. It also allowed the investigation of the predictability of Loran C time difference variation (i.e. the repeatability and magnitude of bias or grid error). Temporal changes in Loran C signal over the short and long term could be determined. The monitors quantified the following signal characteristics:

> Signal availability

> Signal strength

> Noise and interference

> Propagation anomalies

> Envelope-to-cycle difference

Sample data was recorded throughout the day every 30 minutes on a Phillips mini-cassette tape recorder. Cassettes were replaced every second day by a local Pemberton Airport volunteer, who forwarded the recorded cassettes to AirBC.

Each Loran data sample consisted of:

- Time Difference (TD) in microseconds
- Signal-to-noise ratios (SNR)
- Tracking mode numbers
- Blink indicators
- Envelope-tracking numbers

### 7.3.2 Ground Tracking Survey Equipment

At the beginning of the MLS/STOL Flight Demonstration Project, it was assumed that the tests should track and record the path of aircraft in three dimensions, as it carried out the MLS approach/departure/missed approach. The following discusses the research undertaken to provide tracking equipment.

#### Inertial Flight Inspection System:

Preliminary enquiries were made with Litton Systems Canada Ltd., who provide Transport Canada with the Litton Inertial Flight Inspection System (IRFIS), used in flight checking navigation aids. The system is a self-contained enroute and terminal navaid calibration system when coupled with normal navaid receivers. It can calibrate Category I, II, and III ILS/MLS or VORTAC systems at a very high accuracy level. The system's high speed data acquisition and computation permit calibration and recalibration to be performed during the same flight. Calibration can be performed in any flying weather. Ground personnel operating tracking equipment are not required. While the IRFIS unit would achieve the tracking accuracy needed, none were currently available for loan for the project. The capital cost of acquiring a unit was estimated to be close to one million dollars.

## Del Norte Trisponder System:

A Del Norte Flying Flagman was suggested as another tracking/ measuring device for the flight demonstration tests. The Del Norte system is a trisponder positioning system. It uses strategically located radio transponders which relay microwave frequency, line-of-sight electronic ranging information to a central digital distance measure unit. The system provides not only latitude and longitude position, but also altitude of an aircraft.

Initial discussions were held with Conair Aviation Ltd., who use the trisponder position system for precise location information needed in aerial applications undertaken by this Specialty air service company. This unit, however, was committed for the period when the MLS/STOL flight tests were to take place. Surnav Corporation, the Canadian distributor of the Del Norte, provided additional information on a later version of the system, and indicated that the National Research Council and deHavilland of Canada had used the Del Norte system in similar track/position measuring tests. Surnav also recommended the McElhanney Group Ltd., surveyors who own a trisponder system and who have considerable experience in using the system in the Canadian North. McElhanney made a proposal to AirBC to use the Del Norte Trisponder System 542. This system provides a line-of-sight range up to 80 km. with a single range accuracy of +- 1 metre. Aircraft position determination by intersection of ranges was estimated to compute +- 2-3 metre accuracy. Ground control stations were proposed to be established along the flight path, using seven remote transponder stations. Two stations would also be established at the airport. The range positioning was to be recorded on computer disc, through an IBM-PC. The positioning system was to be calibrated in the field. The data recorded would be at 1 to 2 second intervals, with real time aircraft position displayed on a monitor, the data stored on disc, and a hard copy print-out showing left and right distances from the proposed navigation line.

The proposed cost to set up and operate the Del Norte system for a two week period was estimated to be $45,000 - $50,000, assuming weather was suitable for the flight tests. In discussions with Transport Canada, Airworthiness, regarding the merits of the tracking/position system proposed by the McElhanney Group, it was suggested that the on-board Flight Data Acquisition Unit data would provide most of the information in the detail needed by Transport Canada. Flight track information could also be obtained with a less accurate system than the Del Norte system for the purposes of the MLS/STOL flight demonstration tests, and for certification purposes.

## Ground Survey System:

The tracking option selected was video camera recording of the aircraft on the approach and missed approach flight profiles. A high resolution Sony Beta video camera, with 8X telescopic lens, was used. A surveyor's cross-hair lens was coupled to the camera lens. The video camera was mounted on a surveyor's theodolite to select accurate bearing and angle information. Locations to track the approaching aircraft were selected at the front azimuth and the back azimuth, to record the accuracy of the flight profiles. Setting the video camera to the correct bearing and angle took considerable survey information to ensure the video reflected the desired track azimuth and glideslope, including any minor parallax errors between the video camera and the survey telescope. Laser survey equipment was used to tie in the location with known geodetic sites in the Pemberton Valley.

The telephoto lens allowed the position of the aircraft to be tracked from a distance of 10 NM with the video camera, when the aircraft landing lights were illuminated. The cross-hair lens could record within feet any observed deviations from course and glideslope. Direct radio communications between the ground station and the aircraft provided voice-over information on the video tape, with regard to DME distance, flight instrument read-out, airspeed, flap settings, and other details. The video camera confirmed the accuracy of the MLS system. Any course or glideslope deviations could be correlated between the flight instrument deviations, and flight deviations noted on the video camera. The cost of the video camera method of tracking, including a surveyor, technician, and video equipment rental, was approximately $10,000.

# 8. FLIGHT PROFILE DEVELOPMENT

This chapter discusses the flight profile development, including the concept design, approach chart, cockpit coordination, and the Flight Manual Supplement.

## 8.1 Concept Design

The Pemberton MLS/STOL approach, departure/missed approach design is complex. Its design evolved over several months with several agencies having a role in its development.

DeHavilland Aircraft of Canada Ltd., Special Projects, developed the first concept design in 1983 for the Pemberton approach. It recognized the steep flight approach characteristics of the DHC-7, and the precision guidance afforded by an MLS system. Computer generated approach diagrams on mylar transparencies, which could be overlaid on 1:50,000 topographic mapping of the Pemberton area, were developed. The approach criteria used was based on the FAA Notice 8260.49. Micronav Ltd. was consulted during the original concept approach designs for their advice on the capabilities of MLS in a mountain valley approach, and for MLS siting recommendations.

These original concept approach diagrams recognized the terrain constraints of the Pemberton Valley, and the need for a steep STOL approach to maintain sufficient terrain clearance. The concept diagrams also recognized that the missed approach segment was likely the most critical segment of the flight profile. The missed approach segment needed precision track guidance, similar to the front course. It also required an aircraft with the climb performance with one engine out, to meet the climb gradient requirements to reach a safe altitude within the air space available in the Pemberton Valley/Lillooet Lake area.

### Original Design Concept

The original deHavilland concept drawing indicated an enroute altitude of 10,000' ASL on a heading of 351° to the initial approach point (IAP) at 6.4 DME, and proceeding outbound on a heading of 297.5° to a final approach point (FAP) of 11.4 DME. At the FAP, a standard right hand procedure turn is executed. Upon completion of the procedure turn, at 10,000', the inbound course is intercepted, and descent begins. The inbound course heading was 117.5°. The glideslope noted was 7.5°. Descent is made to a Decision Height (DH) of 500' AGL. A visual landing is made from the DH, identified with an NDB in place of a middle marker, located at 0.7 DME. The missed approach started at the DH, with a climbing left turn to 10,000' via a 067° track. At 6.5 DME, a right turn is executed to a heading of 113.7°, to a second NDB on Lillooet Lake (12.4 DM[illegible]. At the second NDB, a right turn to 160.5° is made, continuing to climb to 10,000', and proceeding directly to GARRE intersection.

This original approach concept was later slightly modified to take into account minor location changes of the ground stations and obstacle clearance revisions.

## Ground Equipment Siting Changes

In order to provide the track accuracy in the missed approach area, a second MLS was required. Traditionally, an MLS BAZ, when installed, is located close to the airport runway to provide missed approach precision guidance. In the Pemberton approach design, however, it was felt that MLS coverage in the Missed Approach Point (MAP) area was critical, as the pilot switched from AZ to BAZ coverage while making a 054° climbing turn to the left. Micronav Ltd. suggested that the second MLS be located at the eastern end of the valley, in order to provide the widest MLS beam width possible in the MAP area. In effect, the second MLS would operate like a front course AZ. A location for the BAZ station was finally selected from a number of alternatives, on a mountain slope some 1,800' above, and 6 NM east of the runway. This higher location not only provides beam coverage, but also provides important line of sight coverage below 1,000' in the vicinity of the MAP and airport. Line of sight RF communications could also be provided from this location to the Lillooet U6 NDB on Lillooet Lake, and the central MLS monitoring station located on the Pemberton Airport.

The Pemberton NDB (Micronav Site #1) was relocated several hundred feet to the northwest, due to property acquisition difficulties at the first desired location. The AZ (Micronav Site #3) was originally located on the south shore of Green River, but changed to the north side of the river, and co-located with the EL (Micronav Site #2) for better MLS coverage and power source considerations. The combined AZ/EL site was also adjusted due to property acquisition considerations. Site #4, airport control centre, was not changed, and it remained on the Pemberton Airport. As noted, several sites were considered for the BAZ. The BAZ site selected (Micronav Site #5) was located on the 2,500' ASL contour on a mountain slope. It is accessible via the Duffy Lake road and a logging road. The Lillooet NDB (Micronav Site #6) was changed to a site southward of the original site on Lillooet Lake, due to the proximity of power lines and a limited construction area, next to the shore of Lillooet Lake. Figure 14 shows the ground station sites.

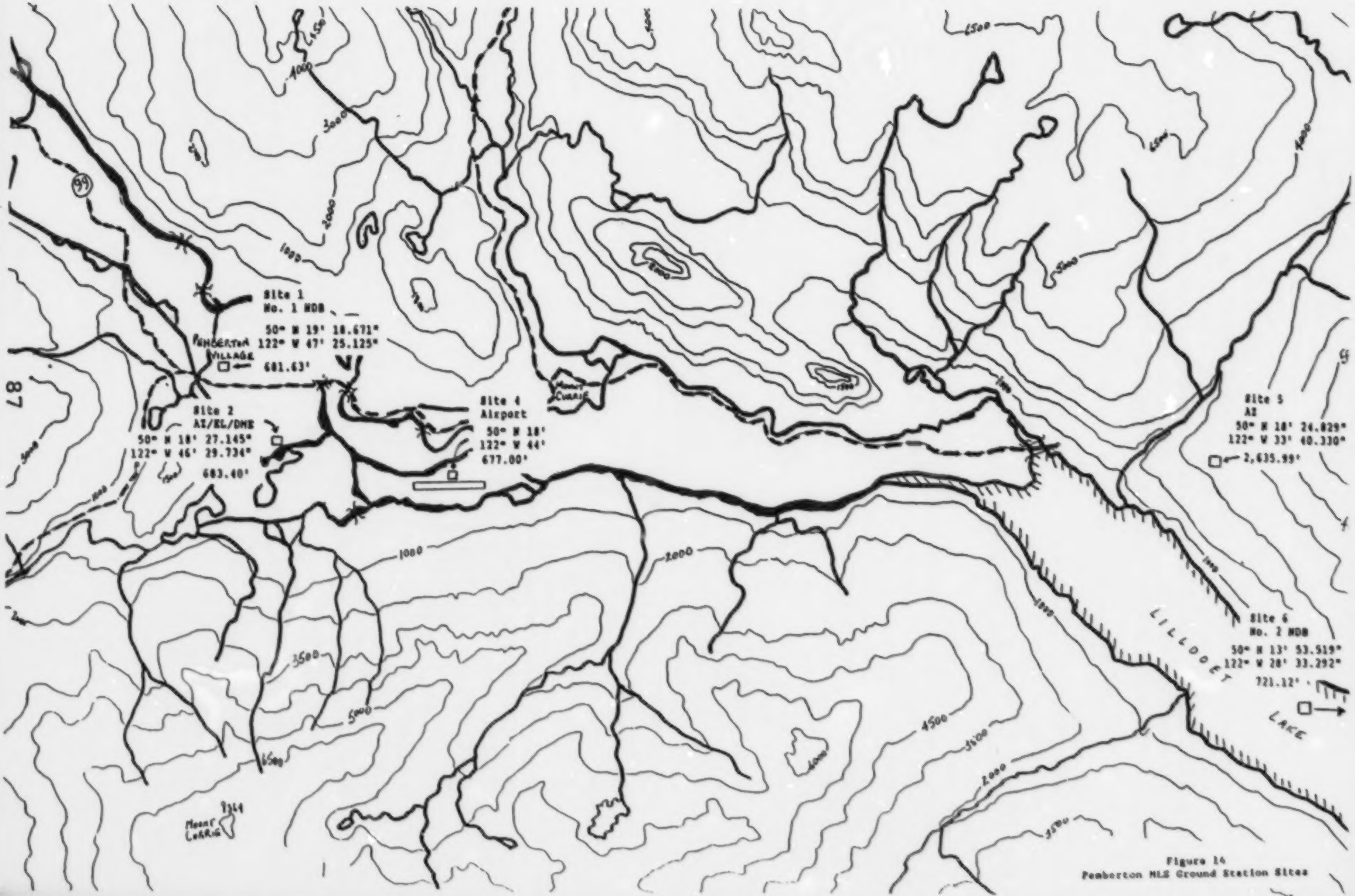

Site 1
No. 1 NDB
50° N 19' 18.671"
122° W 47' 25.125"
681.63'
PEMBERTON VILLAGE
Site 2
AZ/EL/DME
50° N 18' 27.145"
122° W 46' 29.734"
683.40'
Site 4
Airport
50° N 18'
122° W 44'
677.00'
MOUNT CURRIE
Site 5
AZ
50° N 18' 24.829"
122° W 33' 40.330"
2,635.99'
Site 6
No. 2 NDB
50° N 13' 53.519"
122° W 28' 33.292"
721.12'
LILLOOET
LAKE
MOUNT CURRIE
9344
99
1000
2000
3000
3500
4000
4500
5000
6500

Figure 14
Pemberton MLS Ground Station Sites

## 8.2 Aircraft Characteristics

Initial flight tests using the deHavilland approach design revealed that some adjustments were needed to take into account the DHC-7 aircraft characteristics and standard airline procedures. AirBC desired the Pemberton approach to be modelled as closely as possible with standard operating practice, to minimize crew training requirements. These initial flight tests indicated that the DHC-7 could accomplish the approach concept in both normal and emergency aircraft configurations.

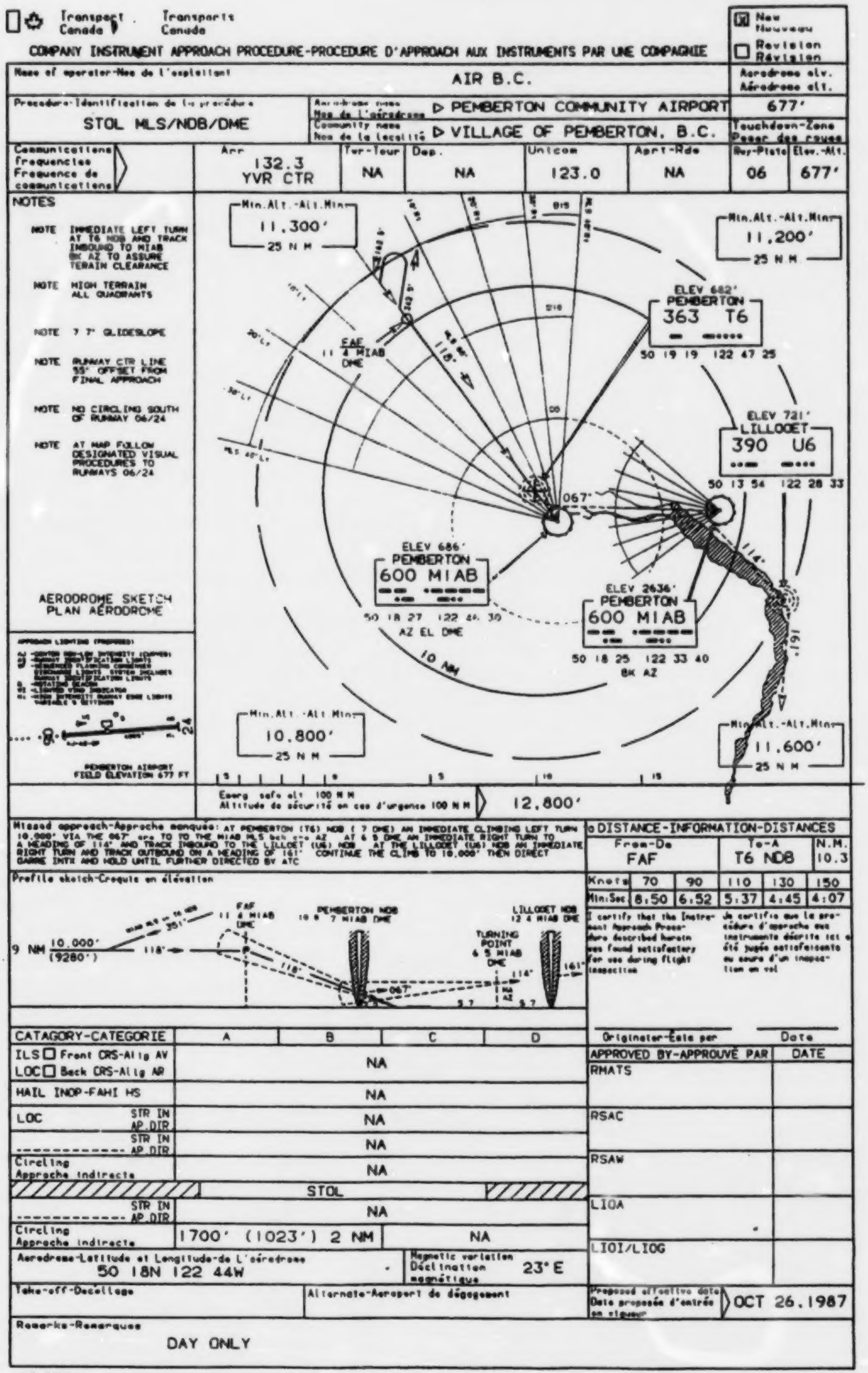
## 8.3 Approach Plate Development

Development of an approach plate for Pemberton was coordinated between deHavilland Canada, Transport Canada, Air Navigation Requirements, Ministry of Transportation and Highways, and AirBC. deHavilland, based on discussions with Transport Canada, Micronav Ltd. and AirBC, submitted an approach plate application form to Transport Canada. The application was submitted on behalf of AirBC. This approach chart reflected the changed locations of the ground stations, and the assigned radio frequencies for the ground stations. Figure 15 shows this company instrument approach procedure application.

It can be noted that the glideslope was increased to 7.7°, and the MAP height increased to 1023' ASL from the original concept drawing. The company submission also reflected a day-only operations, with no lead-in approach lights, which had been incorporated in the original concept diagram.

The Ministry of Transportation and Highways in Victoria operated a Beechcraft King Air simulator for its government air operations, and offered the use of it to AirBC. The Ministry temporarily modified the simulator to more accurately reflect the speed and flight characteristics of the DHC-7, and used the simulator to develop various flight profiles which could be incorporated into the approach plate. The simulator was also used by AirBC flight crews to develop cockpit procedures during the approach and to gain experience on executing the approach procedure. The Ministry also examined the impact on MAP height with non-STOL aircraft using the Pemberton approach, such as the DHC-8 and the Cessna Citation executive jet. The MAP height with non-STOL aircraft is significantly raised, in that the approach is only a cloud breaking procedure, and not a precision approach. Figure 16 shows the Ministry of Transportation and Highways approach chart conducted for planning purposes and use in initial simulator tests.

# Figure 15
# AirBC Pemberton Instrument Approach Procedure



Min.Alt.-Alt.Min.
11,300'
25 N M
Min.Alt.-Alt.Min.
11,200'
25 N M
ELEV 682'
PEMBERTON
363 T6
50 19 19 122 47 25
ELEV 721'
LILLOOET
390 U6
50 13 54 122 28 33
FAF
11 4 MIAB
DME
067°
118°
114°
161°
ELEV 686'
PEMBERTON
600 MIAB
50 18 27 122 44 30
AZ EL DME
ELEV 2636'
PEMBERTON
600 MIAB
50 18 25 122 33 40
BK AZ
10 NM
Min.Alt.-Alt.Min.
10,800'
25 N M
Min.Alt.-Alt.Min.
11,600'
25 N M
AERODROME SKETCH
PLAN AERODROME
24
PEMBERTON AIRPORT
FIELD ELEVATION 677 FT
Profile sketch-Croquis en élévation
FAF
11 4 MIAB
DME
PEMBERTON NDB
10 8 7 MIAB DME
LILLOOET NDB
12 4 MIAB DME
TURNING POINT
6 5 MIAB DME
9 NM 10,000' (9280')
351°
118°
067°
114°
161°

Transport Canada / Transports Canada

COMPANY INSTRUMENT APPROACH PROCEDURE-PROCEDURE D'APPROACH AUX INSTRUMENTS PAR UNE COMPAGNIE

☒ New Nouveau
☐ Revision Révision

| | | |
|---|---|---|
| Name of operator-Nom de l'exploitant | AIR B.C. | Aerodrome elv. Aérodrome elt. |
| Procedure-Identification de la procédure: STOL MLS/NDB/DME | Aerodrome name / Nom de l'aérodrome: ▷ PEMBERTON COMMUNITY AIRPORT | 677' |
| | Community name / Nom de la localité: ▷ VILLAGE OF PEMBERTON, B.C. | Touchdown-Zone |

| Communications frequencies Fréquence de communications ▷ | Arr | Twr-Tour | Dep. | Unicom | Aprt-Rdo | Rwy-Piste | Elev.-Alt. |
|---|---|---|---|---|---|---|---|
| | 132.3 YVR CTR | NA | NA | 123.0 | NA | 06 | 677' |

NOTES

NOTE IMMEDIATE LEFT TURN AT T6 NDB AND TRACK INBOUND TO MIAB BK AZ TO ASSURE TERAIN CLEARANCE

NOTE HIGH TERRAIN ALL QUADRANTS

NOTE 7 7° GLIDESLOPE

NOTE RUNWAY CTR LINE 35° OFFSET FROM FINAL APPROACH

NOTE NO CIRCLING SOUTH OF RUNWAY 06/24

NOTE AT MAP FOLLOW DESIGNATED VISUAL PROCEDURES TO RUNWAYS 06/24

APPROACH LIGHTING (PROPOSED)

Emerg safe alt 100 N M / Altitude de sécurité en cas d'urgence 100 N M ▷ 12,800'

Missed approach-Approche manquée: AT PEMBERTON (T6) NDB ( 7 DME) AN IMMEDIATE CLIMBING LEFT TURN 10,000' VIA THE 067° arc TO TO THE MIAB MLS bck crs AZ AT 6 5 DME AN IMMEDIATE RIGHT TURN TO A HEADING OF 114° AND TRACK INBOUND TO THE LILLOOET (U6) NDB AT THE LILLOOET (U6) NDB AN IMMEDIATE RIGHT TURN AND TRACK OUTBOUND ON A HEADING OF 161° CONTINUE THE CLIMB TO 10,000' THEN DIRECT GARRE INTX AND HOLD UNTIL FURTHER DIRECTED BY ATC

DISTANCE-INFORMATION-DISTANCES

| From-De | | To-A | | N.M. |
|---|---|---|---|---|
| FAF | | T6 NDB | | 10.3 |

| Knots | 70 | 90 | 110 | 130 | 150 |
|---|---|---|---|---|---|
| Min:Sec | 8:50 | 6:52 | 5:37 | 4:45 | 4:07 |

I certify that the Instrument Approach Procedure described herein was found satisfactory for use during flight inspection

Je certifie que la procédure d'approche aux instruments décrite ici a été jugée satisfaisante au cours d'un inspection en vol

Originator-Établi par ______ Date ______

| CATAGORY-CATEGORIE | A | B | C | D |
|---|---|---|---|---|
| ILS ☐ Front CRS-Alig AV<br>LOC ☐ Back CRS-Alig AR | NA | | | |
| HAIL INOP-FAHI HS | NA | | | |
| LOC STR IN AP DIR | NA | | | |
| STR IN AP DIR | NA | | | |
| Circling Approche indirecte | NA | | | |
| STOL | | | | |
| STR IN AP DIR | NA | | | |
| Circling Approche indirecte | 1700' (1023') 2 NM | | NA | |

| APPROVED BY-APPROUVÉ PAR | DATE |
|---|---|
| RMATS | |
| RSAC | |
| RSAW | |
| LIOA | |
| LIOI/LIOG | |

Aerodrome-Latitude et Longitude-de L'aérodrome: 50 18N 122 44W

Magnetic variation Déclinaison magnétique: 23°E

Take-off-Décollage

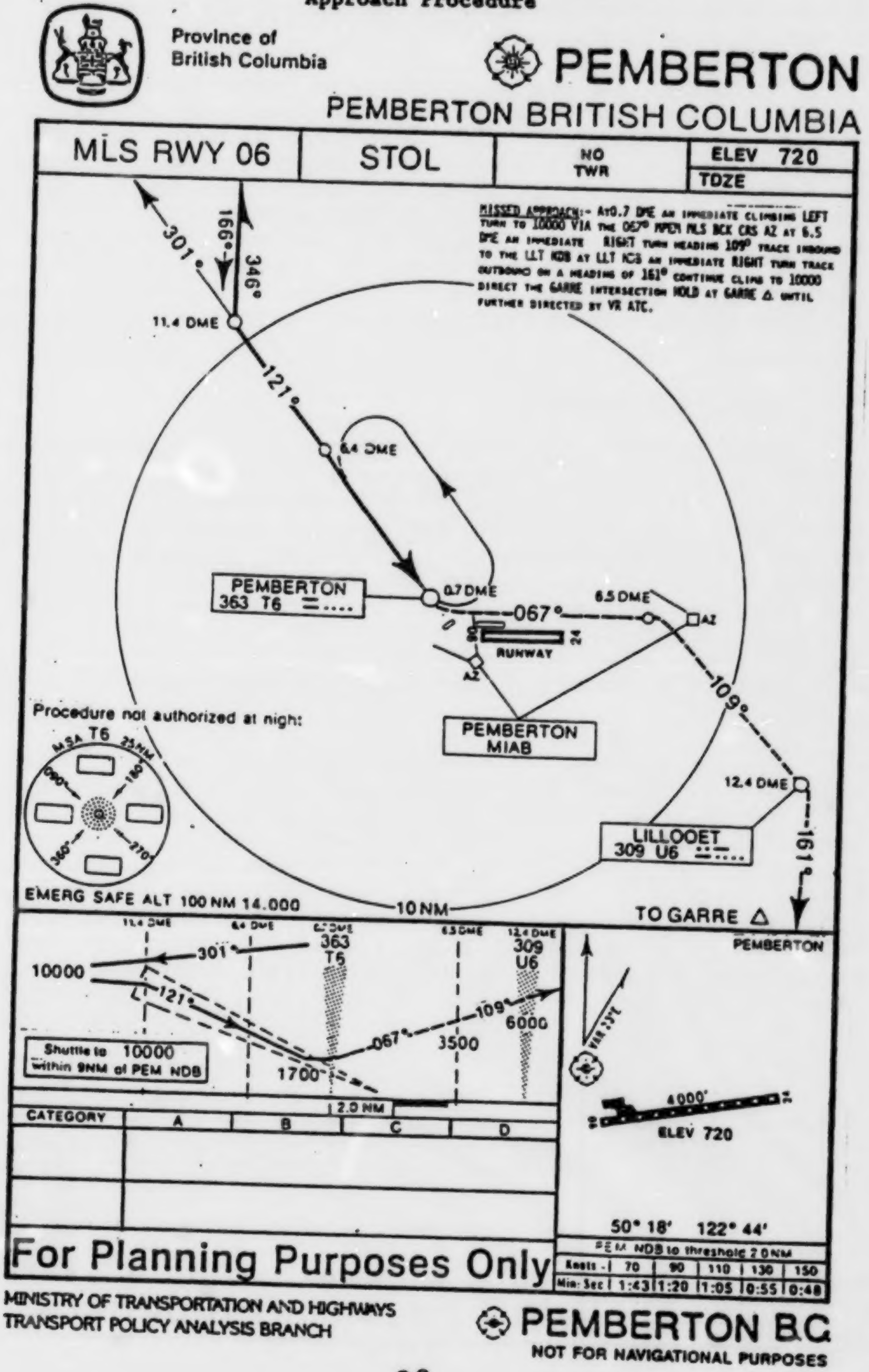
Alternate-Aeroport de dégagement

Proposed effective date / Date proposée d'entrée en vigueur ▷ OCT 26,1987

Remarks-Remarques: DAY ONLY

26-0284

**Figure 16**
**Ministry of Transportation and Highways**
**Approach Procedure**


Province of
British Columbia
PEMBERTON
PEMBERTON BRITISH COLUMBIA
MLS RWY 06
STOL
NO TWR
ELEV 720
TDZE
301°
166°
346°
11.4 DME
121°
8.4 DME
PEMBERTON
363 T6
0.7 DME
067°
6.5 DME
AZ
RUNWAY
06
24
AZ
109°
PEMBERTON MIAB
Procedure not authorized at night
MSA T6 25NM
090°
180°
270°
360°
12.4 DME
LILLOOET
309 U6
161°
EMERG SAFE ALT 100 NM 14.000
10 NM
TO GARRE △
11.4 DME
8.4 DME
0.7 DME
6.5 DME
12.4 DME
363
T6
309
U6
10000
301°
121°
109°
6000
067°
3500
1700
Shuttle to 10000 within 9NM of PEM NDB
2.0 NM
CATEGORY
A
B
C
D
PEMBERTON
VAR 23°E
4000'
06
24
ELEV 720
50° 18'
122° 44'
For Planning Purposes Only
MINISTRY OF TRANSPORTATION AND HIGHWAYS
TRANSPORT POLICY ANALYSIS BRANCH
PEMBERTON B.C.
NOT FOR NAVIGATIONAL PURPOSES

MISSED APPROACH:- AT 0.7 DME AN IMMEDIATE CLIMBING LEFT TURN TO 10000 VIA THE 067° APCH MLS BCK CRS AZ AT 6.5 DME AN IMMEDIATE RIGHT TURN HEADING 109° TRACK INBOUND TO THE LLT NDB AT LLT NDB AN IMMEDIATE RIGHT TURN TRACK OUTBOUND ON A HEADING OF 161° CONTINUE CLIMB TO 10000 DIRECT THE GARRE INTERSECTION HOLD AT GARRE △ UNTIL FURTHER DIRECTED BY VR ATC.

PEM NDB to threshold 2.0 NM

| Knots | 70 | 90 | 110 | 130 | 150 |
|---|---|---|---|---|---|
| Min: Sec | 1:43 | 1:20 | 1:05 | 0:55 | 0:48 |

AirBC also used an approach chart design which was developed during the initial flight tests. Blank approach plate forms were used which could be changed as the result of the flight tests. An example of an early approach chart used by AirBC is shown in Figure 17.

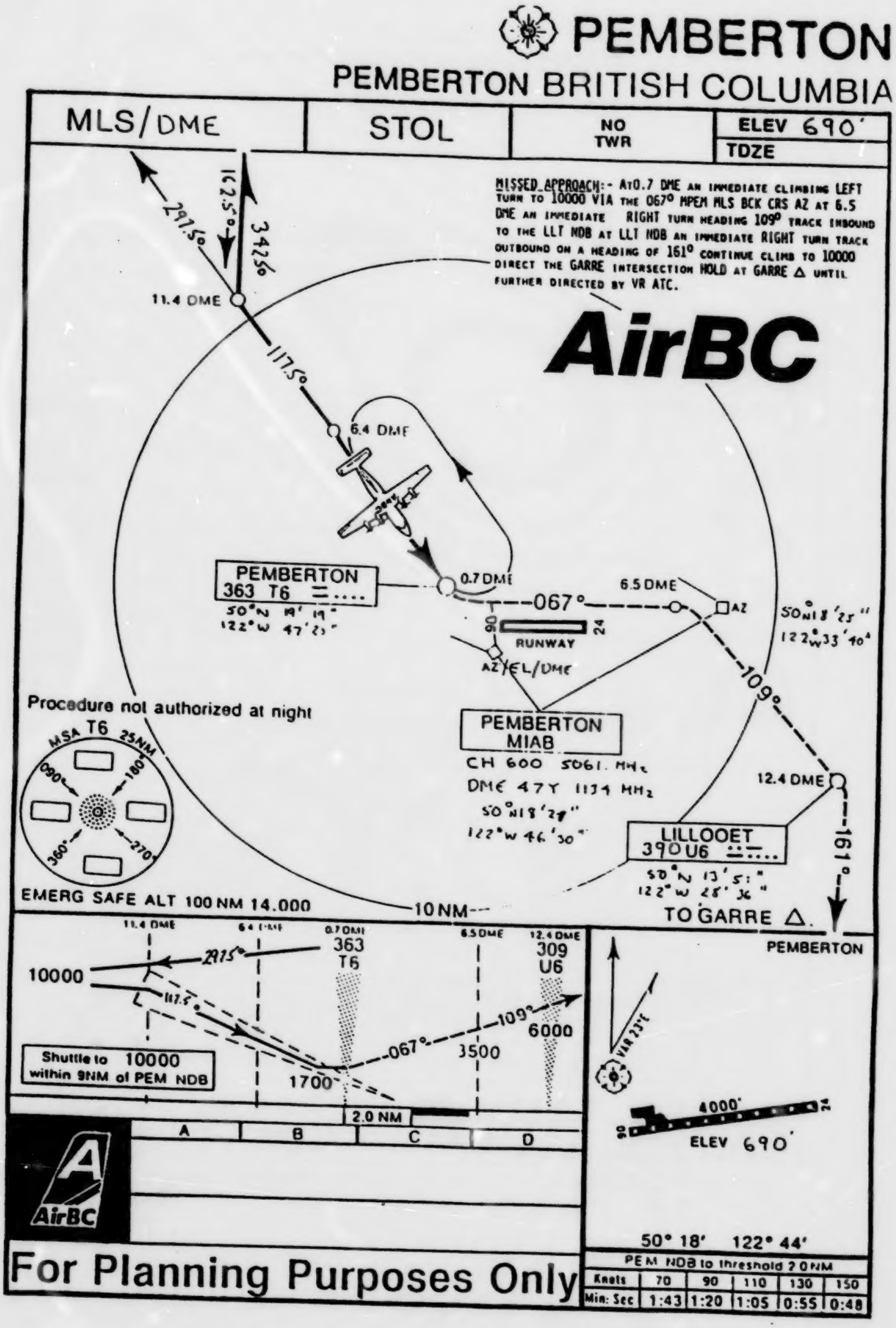
Transport Canada conducted an extensive examination of obstacle clearance needs during all phases of the flight profile - enroute, approach, and departure/missed approach. This examination resulted in slight flight course changes on the approach and missed approach, to meet obstacle clearance needs. It also resulted in specific recommendations for climb gradients in the departure/missed approach segment. Transport Canada, Pacific Region, submitted a draft approach plate to Ottawa for comments and approval. Figure 18 shows the draft approach plate for Pemberton. This draft approach plate is still in effect.

## 8.4 Cockpit Procedures

Cockpit procedures for the Pemberton MLS/STOL approach were based on AirBC's standard operating procedures and company approved aircraft check list sequences wherever possible. Additional information on MLS approach criteria and its impact on cockpit procedures was obtained from the Chief Pilot of Rocky Mountain Airways in Denver, Colorado, who has experience with the Colorado MLS mountain valley approaches operated by Rocky Mountain Airways. Information on the Valdez, Alaska MLS approach was also obtained from the former DHC-7 Chief Pilot with ERA, who operated the aircraft into Valdez in the early 1980's.

Cockpit procedures developed by AirBC were tried out during the initial flight tests, and were modified as necessary with each successive flight test. These procedures included flight crew coordination, navaid frequency set-up, cockpit checks, course and altitude cross checks, flight instrument monitoring, flight commands, MLS signal validation, and other cockpit procedures. An example of cockpit procedure development is shown in Figure 19. This figure illustrates the cockpit procedures used during an initial flight test.

Figure 17
AirBC Early Pemberton Approach Chart


PEMBERTON
PEMBERTON BRITISH COLUMBIA
MLS/DME
STOL
NO TWR
ELEV 690'
TDZE
AirBC
162.5°
342.5°
297.5°
11.4 DME
117.5°
6.4 DME
0.7 DME
PEMBERTON
363 T6
50°N 19' 19"
122°W 47' 23"
067°
6.5 DME
AZ
50°N 18' 25"
122°W 33' 40"
06
24
RUNWAY
AZ/EL/DME
109°
Procedure not authorized at night
PEMBERTON
MIAB
CH 600 5061. MHz
DME 47Y 1134 MHz
50°N 18' 27"
122°W 46' 30"
12.4 DME
LILLOOET
390 U6
50°N 13' 51"
122°W 28' 36"
161°
TO GARRE △.
MSA T6 25NM
090°
180°
360°
270°
EMERG SAFE ALT 100 NM 14.000
10 NM
11.4 DME
6.4 DME
0.7 DME
363
T6
6.5 DME
12.4 DME
309
U6
10000
297.5°
117.5°
067°
109°
6000
3500
1700
Shuttle to 10000 within 9NM of PEM NDB
2.0 NM
A
B
C
D
AirBC
PEMBERTON
VAR 23°E
4000'
06
24
ELEV 690'
50° 18' 122° 44'

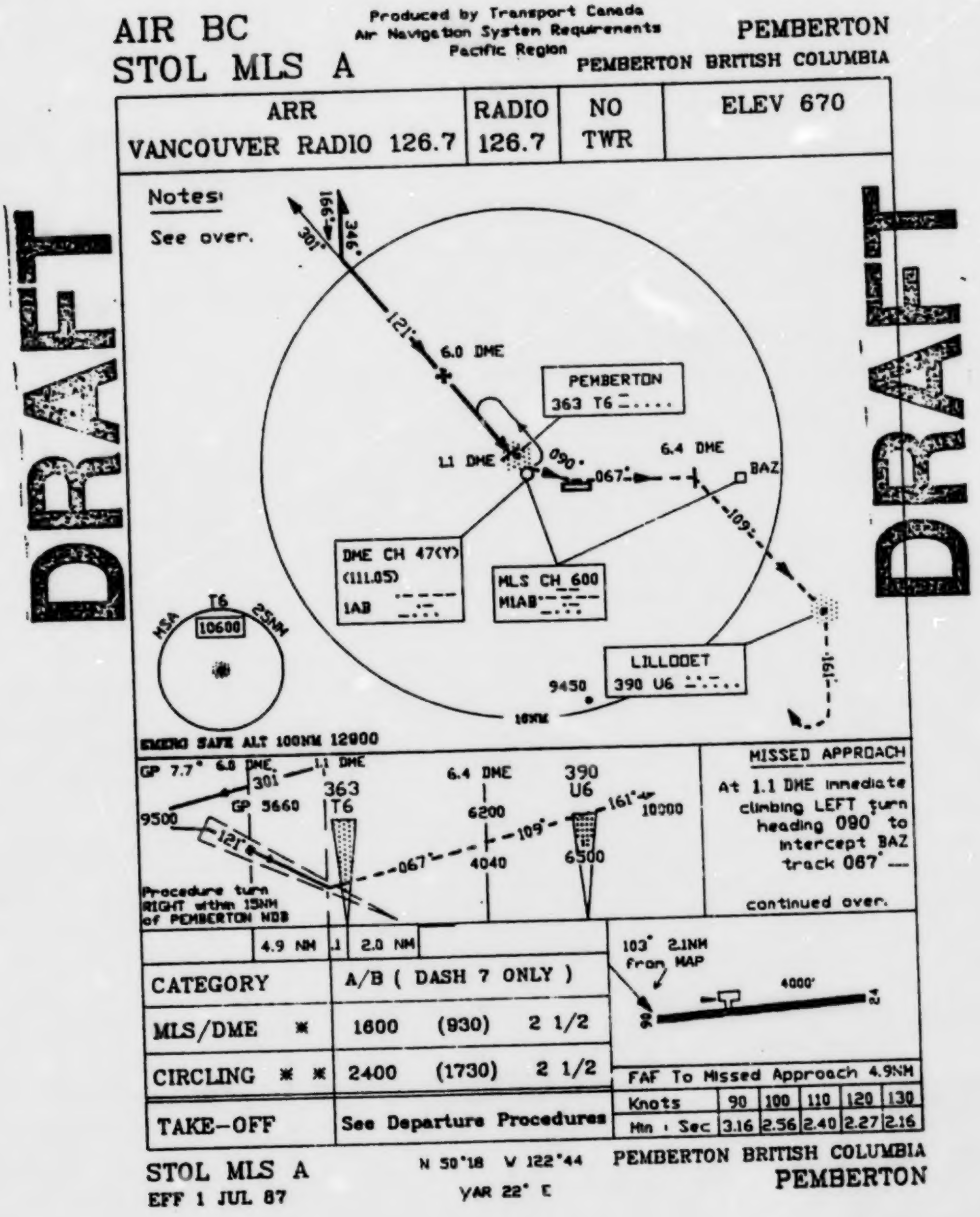
MISSED APPROACH:- At 0.7 DME AN IMMEDIATE CLIMBING LEFT TURN TO 10000 VIA THE 067° MPEM MLS BCK CRS AZ AT 6.5 DME AN IMMEDIATE RIGHT TURN HEADING 109° TRACK INBOUND TO THE LLT NDB AT LLT NDB AN IMMEDIATE RIGHT TURN TRACK OUTBOUND ON A HEADING OF 161° CONTINUE CLIMB TO 10000 DIRECT THE GARRE INTERSECTION HOLD AT GARRE △ UNTIL FURTHER DIRECTED BY VR ATC.

For Planning Purposes Only

PEM NDB to threshold 2 0 NM

| Knots | 70 | 90 | 110 | 130 | 150 |
|---|---|---|---|---|---|
| Min: Sec | 1:43 | 1:20 | 1:05 | 0:55 | 0:48 |

**Figure 18**
**Transport Canada Draft Pemberton Approach Chart**



AIR BC
STOL MLS A

Produced by Transport Canada
Air Navigation System Requirements
Pacific Region

PEMBERTON
PEMBERTON BRITISH COLUMBIA

| ARR | RADIO | NO | ELEV 670 |
|---|---|---|---|
| VANCOUVER RADIO 126.7 | 126.7 | TWR | |

Notes:
See over.

EMERG SAFE ALT 100NM 12900

MISSED APPROACH
At 1.1 DME immediate climbing LEFT turn heading 090° to intercept BAZ track 067° —
continued over.

Procedure turn RIGHT within 15NM of PEMBERTON NDB

| | 4.9 NM | .1 | 2.0 NM |
|---|---|---|---|

| | | | |
|---|---|---|---|
| CATEGORY | A/B ( DASH 7 ONLY ) | | |
| MLS/DME * | 1600 | (930) | 2 1/2 |
| CIRCLING * * | 2400 | (1730) | 2 1/2 |
| TAKE-OFF | See Departure Procedures | | |

FAF To Missed Approach 4.9NM

| Knots | 90 | 100 | 110 | 120 | 130 |
|---|---|---|---|---|---|
| Min : Sec | 3.16 | 2.56 | 2.40 | 2.27 | 2.16 |

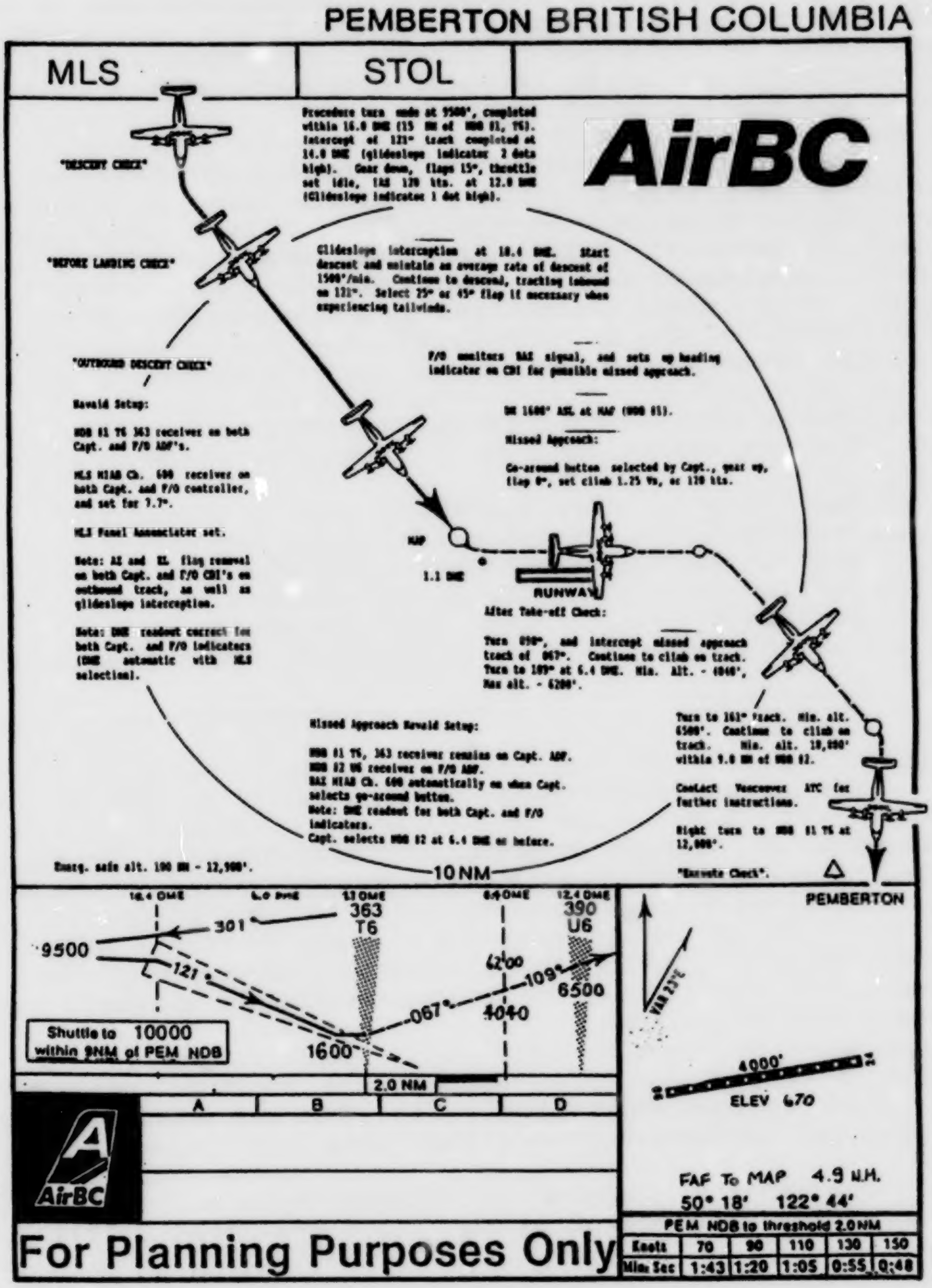
STOL MLS A
EFF 1 JUL 87

N 50°18 W 122°44
VAR 22° E

PEMBERTON BRITISH COLUMBIA
PEMBERTON

DRAFT
DRAFT
166°
346°
301°
121°
6.0 DME
PEMBERTON
363 T6
1.1 DME
090°
067°
6.4 DME
BAZ
109°
DME CH 47(Y)
(111.05)
IAB
MLS CH 600
MIAB
LILLOOET
390 U6
9450
161°
10NM
MSA
T6
25NM
10600
GP 7.7° 6.0 DME
301
1.1 DME
363
T6
GP 5660
9500
121°
6.4 DME
6200
4040
067°
109°
390
U6
6500
161°
10000
103° 2.1NM from MAP
4000'
06
24

**Figure 19**
**Pemberton Cockpit Procedure Development**



PEMBERTON BRITISH COLUMBIA

Procedure turn made at 9500', completed within 16.0 DME (15 NM of NDB #1, T6). Intercept of 121° track completed at 14.0 DME (glideslope indicator 2 dots high). Gear down, flaps 15°, throttle set idle, IAS 120 kts. at 12.0 DME (Glideslope indicator 1 dot high).

Glideslope interception at 10.4 DME. Start descent and maintain an average rate of descent of 1500'/min. Continue to descend, tracking inbound on 121°. Select 25° or 45° flap if necessary when experiencing tailwinds.

F/O monitors BAZ signal, and sets up heading indicator on CDI for possible missed approach.

DH 1600' ASL at MAP (NDB #1).

Missed Approach:

Go-around button selected by Capt., gear up, flap 0°, set climb 1.25 Vs, or 120 kts.

"OUTBOUND DESCENT CHECK"

Navaid Setup:

NDB #1 T6 363 receiver on both Capt. and F/O ADF's.

MLS MIAB Ch. 600 receiver on both Capt. and F/O controller, and set for 7.7°.

MLS Panel Annunciator set.

Note: AZ and EL flag removal on both Capt. and F/O CDI's on outbound track, as well as glideslope interception.

Note: DME readout correct for both Capt. and F/O indicators (DME automatic with MLS selection).

After Take-off Check:

Turn 090°, and intercept missed approach track of 067°. Continue to climb on track. Turn to 109° at 6.4 DME. Min. Alt. - 4040', Max alt. - 6200'.

Missed Approach Navaid Setup:

NDB #1 T6, 363 receiver remains on Capt. ADF.
NDB #2 U6 receiver on F/O ADF.
BAZ MIAB Ch. 600 automatically on when Capt. selects go-around button.
Note: DME readout for both Capt. and F/O indicators.
Capt. selects NDB #2 at 6.4 DME or before.

Turn to 161° track. Min. alt. 6500'. Continue to climb on track. Min. alt. 10,000' within 9.0 NM of NDB #2.

Contact Vancouver ATC for further instructions.

Right turn to NDB #1 T6 at 12,000'.

"Enroute Check".

Emerg. safe alt. 100 NM - 12,000'.

MLS
STOL
AirBC
"DESCENT CHECK"
"BEFORE LANDING CHECK"
MAP
1.1 DME
RUNWAY
10 NM
PEMBERTON
16.4 DME
6.0 DME
1.1 DME
6.4 DME
12.4 DME
363
T6
390
U6
9500
301°
121°
1600
067°
6200
4040
109°
6500
Shuttle to 10000 within 9NM of PEM NDB
2.0 NM
A
B
C
D
AirBC
VAR 23°E
4000'
ELEV 670
FAF To MAP 4.9 N.M.
50° 18' 122° 44'

For Planning Purposes Only

PEM NDB to threshold 2.0NM

| Knots | 70 | 90 | 110 | 130 | 150 |
|---|---|---|---|---|---|
| Min Sec | 1:43 | 1:20 | 1:05 | 0:55 | 0:48 |

## 8.5 Aircraft Flight Manual Supplement

A supplement to the DHC-7 aircraft flight manual was drafted by AirBC to accommodate the requirements of operating the aircraft with MLS equipment. The flight supplement is to be approved by Transport Canada, Airworthiness/Air Carrier Inspection, and is an integral component of the flight manual when the MLS equipment is used.

Guidance for drafting the flight supplement was based on information provided by Rocky Mountain Airways, which addressed the Singer/Talar MLS in their DHC-7 Flight Manual, and their Training Manual. Bendix-King provided a copy of the flight manual supplement for the Beechcraft King Air 200 equipped with Bendix-King MLS-21 receivers. The AirBC Flight Manual Supplement for the DHC-6-100, equipped with Bendix-King MLS-20, was also used as a guide.

The AirBC Flight Manual Supplement for DHC-7 with MLS included the following:

| | |
|---|---|
| Section I | General |
| Section II | Limitations |
| Section III | Emergency Procedures |
| Section IV | Normal Procedures |
| Section V | Abnormal Procedures |
| | A. Operating Precautions |
| | B. Flags |
| Section VI | System Description |

The flight manual supplement was forwarded to Transport Canada for their comments. Transport Canada, Airworthiness, issued to AirBC a draft paper entitled "Special Conditions for DHC-7 Steep Approach at 7.7 Degrees". This paper addresses airworthiness requirements in order to obtain approval of steep approach using an approach path angle of 7.7°, which is 0.2° over the original aircraft certification. The special conditions recommended by Transport Canada in their paper are summarized as follows:

- All engines operating climb (minimum steady gradient of climb conditions - not less than 3.2%).

- One engine inoperative missed approach climb (minimum steady gradient of climb - note less that 2.7%).

> Controllability and manoeuvrability:

a. complete an approach without displaying any hazardous characteristics in the following conditions:

  - approach angles of 2° above and 2° below selected approach path angle, at $V_{app}$.

  - $V_{app}$ +10 and -5 kts. at the selected approach path angle.

b. transition to missed approach climb after failure of critical engine while the aircraft is established on a steady approach at approach path angles of 2° above and 2° below the selected steep approach path angle.

c. demonstrate in all engine steep approach configuration and not less than 1.31 g (40° bank turn) at Vapp and symmetric power. The demonstration to be at the most critical weight and C of G position.

d. transition from steep approach to the final landing configuration to be shown for all engines operating and following critical engine failure.

> Flight Manual - Supplement for steep approach to include:

a. the more limiting of -

  - landing WAT conditions derived in accordance with all engines operating climb; or

  - landing WAT conditions derived in accordance with one engine inoperative missed approach climb.

b. appropriate limitations, normal, abnormal and emergency procedures.

c. statement that the limitations, procedures, and performance are predicated on the use of a guidance system suitable for visual reference or an approved steep approach instrument landing system, as applicable.

## 8.6 Flight Crew Qualifications

A flight crew training syllabus to conduct MLS/STOL mountain valley approaches with the DHC-7 was developed by AirBC to enhance flight crew qualifications. An Operating Manual for the MLS was written for flight crew training purposes. The manual provides a basic overview of how the MLS works. It shows the interface between MLS and the flight instrument and outlines the MLS components - angle receiver, control display, annunciator control, and antenna. The manual provides operating precautions as well as operating controls and display features. The operating controls and display section also describes the function of each of the controls.

A Flight Training Supplement was also written by AirBC. The flight training supplement refers to AirBC's Operations Manual, as the principal guide to training and practice, with regard to manoeuvres and procedures for the DHC-7. The supplement, however, does address the initial qualifications check and annual proficiency check using the MLS approach at Pemberton. These checks include a missed approach with a simulated engine failure at gross weight, including a transition from approach to missed approach. It also provides a check of a steep MLS approach under various power and flap configurations.

## 9. FLIGHT TEST PROGRAM

AirBC conducted nearly 80 hours of flight tests during the MLS/STOL Flight Demonstration Project. This chapter discusses the flight test program. It outlines the initial flight tests, the main flight evaluation tests, and the Transport Canada flight tests. Additional flight tests conducted to solve back azimuth reception problems are described in the next chapter.

### 9.1 Initial Flight Tests

About 15 hours of flight testing was conducted in the initial flight test program. This initial flight test program was designed to confirm basic MLS signal reception and to develop a flight profile for future tests. Some flight failure modes were also simulated in the initial test period. (See Appendix B for details.)

### 9.2 Main Flight Test Evaluation

The main flight tests were conducted between April 17th and July 28th, when about 45 hours of flight testing were conducted on C-GXPO. Most of the tests were conducted in July. These flight tests were conducted with the research equipment installed on the aircraft, as well as the MLS and Loran C receivers. Each test flight was about four hours in duration in flight time. (See Appendix B for details.)

### 9.3 Initial Transport Canada Flight Tests

Transport Canada, Airworthiness, Ottawa, conducted a series of initial flight test evaluations during the week of July 27, 1987. Weather conditions and a lightning-damaged BAZ synchronization transmitter chip necessitated that three test flights be conducted over a week-long period. One test flight was conducted using the Nanaimo MLS facility (eg. signal/range reception). The tests performed are outlined in Appendix B.

### 9.4 Problems Experienced During Flight Tests

There were a number of factors which presented problems during the flight demonstration tests. These problems were not fully appreciated when the Research Work Plan was developed for the MLS/STOL Flight Demonstration Project.

- **Test Equipment Availability** - It was not known at the beginning of the project which test equipment would be the most appropriate to use for the demonstration, and its availability. Since the project was unique, there was little guidance, and considerable time in the initial weeks of the program was spent on examining test equipment options and deciding on the most suitable, given the constraints of budget/time and the required accuracy of the test results. In some cases, the selected equipment was not available. There are also only limited Transport Canada criteria as to what factors were to be tested, how they were to be recorded, and what standards and criteria would be applicable.

- **Equipment Loading/Unloading Time** - The MLS and other test equipment had to be installed for each flight, and removed upon completion of the test. The aircraft could not be used for revenue flights with any of the test equipment left on board. Prior to each test flight, some 6 hours was required to load and install the equipment, and to check its operation. Similarly, up to 4 hours was required to take the equipment off the aircraft and store it for the next flight demonstration. The time to load/unload the equipment impacted on the aircraft availability. The aircraft was available for tests for several hours a day, but not sufficient to load/unload the equipment and conduct the necessary tests. Loading/unloading equipment also resulted in some minor damage and/or missing equipment.

- **Weather** - VFR weather conditions were not only required in the Pemberton Valley for the tests, but also the enroute portion between Vancouver and Pemberton. During the flight tests, the aircraft with the MLS equipment onboard did not meet airworthiness standards, therefore IFR enroute flights could not be planned, and then cancelled in the vicinity of Pemberton, when VFR conditions could be encountered. Despite conducting the demonstration flights in the Spring and Summer months, weather problems frequently interfered with the test program. Several flights were conducted as far as Whistler/Alta Lake before weather conditions resulted in cancellation of the demonstration, and a return to Vancouver. This resulted in several man-hours in preparing for the flight, flight time in an attempt to reach Pemberton and return, and man-hours to unload the equipment without conducting a demonstration test. On several occasions, test personnel assembled in Vancouver from Eastern Canada and the U.S., waited a week or more before weather was suitable for a demonstration flight. Each day equipment would be loaded on the aircraft in anticipation of a test flight if the weather cleared.

Expenses were incurred without obtaining test results in cancelled flights.

- Aircraft Availability - Originally, it was planned that C-GXPO would be taken off revenue service at the end of March, 1987, for installation of the MLS equipment, and that the demonstration tests would be conducted during April/May. At the end of May, the aircraft would have returned to revenue service. Delays in the MLS installation, test equipment availability, and weather conditions caused the flight demonstration program to be extended considerably. C-GXPO, however, had to return to revenue service. The aircraft, then, was only available during the weekend, and for certain hours of the weekdays. However, due to fleet mechanical problems and other reasons, C-GXPO frequently had to be used for revenue flights during periods when the aircraft should have been available. C-GXPO's own scheduled maintenance requirements also affected aircraft availability.

- Coordination Requirements - It was anticipated that coordination between the various interested groups would be a task. As the flight tests progressed, however, the coordination efforts significantly increased. Aircraft availability, weather conditions, and test equipment changes, necessitated frequent coordination to ensure that all parties were informed of the latest flight test developments, and whether certain flight tests would proceed or be cancelled. This included informing personnel with Bendix-King, the U.S. Coast Guard, and Megapulse in the U.S., and Transport Canada (Ottawa), TDC (Montreal), and Micronav (Sydney). Coordination also required that flight test notes, flight test progress meeting minutes, and other correspondence be distributed in a timely manner to ensure all parties were informed of the steps being taken, and the responsibilities assigned for future flight tests.

- Availability of Key Personnel - It became evident that the availability of key personnel during the flight tests was crucial to the success of the tests. Micronav technicians were not available for making adjustments to the ground equipment during some of the tests. AirBC flight crews, with MLS/STOL experience, from time to time were not readily available, due to other line or training duties. AirBC Avionics and technical support was also limited, due to the volume of fleet avionics maintenance being undertaken, summer vacation allocations, and having shift personnel familiar with the MLS installation on hand. Technical advice from Bendix-King, deHavilland, and

Transport Canada all depended on the individual schedules of these advisors, and their ability to tie in their schedules with an uncertain flight demonstration schedule.

## 10. BACK AZIMUTH RECEPTION PROBLEM

During the MLS/STOL flight demonstration tests, it was evident that a back azimuth reception problem existed in the missed approach area. Demonstration flights experienced momentary flags in this coverage area. These momentary flags would occur randomly throughout the BAZ coverage area, and at all altitudes. The frequency of flag occurrence, however, increased in the vicinity of the Pemberton Airport at the lower altitudes during the climb out procedure. This chapter discusses the problem, additional flight tests which were conducted, and the test results. Work steps to solve the problem are presented.

### 10.1 Synopsis of Problem

The problem was not observed in the initial Twin Otter or Transport Canada tests, since these aircraft were equipped with Bendix-King MLS 20 receivers, which do not have an automatic BAZ feature. When Transport Canada or AirBC DHC-6 tests were done in the BAZ coverage area, the front AZ transmitter was turned off, and the BAZ tested in isolation. The problem was first experienced when C-GXPO was test flown with the Bendix-King MLS 21 receivers.

Several hours of testing were conducted in C-GXPO in the BAZ coverage area to determine if there was a pattern to the flagging. Flights were flown at various altitudes back and forth in the BAZ coverage area, and the flagging was logged on the FDAU computer print-out, as well as the flight notes being taken during the test. Tests were also conducted at various flap configurations, and with electrical power voltage changes, to determine if the aircraft was the cause of the flagging problem. The Bendix-King MLS-21 receivers were also changed, as were the antennae and antennae leads, to see if the problem still persisted. The MLS ground transmitter was also turned off and on, including shutting down the front AZ.

Shutting down the front AZ did improve the BAZ reception, which indicated that front AZ signal was being received in the BAZ area. Reflection of the AZ signal in the missed approach segment could cause a distortion of the BAZ signal. The BAZ transmitter was tilted down and up to see if coverage could be improved. The Out-of-Coverage Indicator (OCI) antenna was also checked to ensure the scanning beam was not reflecting off nearby mountains. The synchronization of communication between the front and back azimuths was also checked. All these additional modifications and flight tests to test the results did not provide a solution to the BAZ flagging problem. At the time of the Transport Canada initial flight test, the BAZ flagging was noted, and it was pointed out that by the time the final flight test was conducted, the BAZ flagging problem had to be resolved. No flags are acceptable for certification.

## 10.2 Additional Flight Tests

Extensive consultation took place between AirBC, Micronav, Bendix-King, and Transport Canada, in an attempt to arrive at a solution to the flagging problem.

Transport Canada's log video recording taken in the back azimuth area, noted the following:

- good signal reception throughout the BAZ area.
- front azimuth signal evident in BAZ area, but weak.
- no reflections of any type were observed.

Transport Canada's recordings were made with the OCI antenna both on and off. Transport Canada's information indicated that the BAZ problem was not significant, but present.

The following were suggested by the Advisory Review Committee as possible sources of BAZ flagging:

1. Data word bit problem.
2. Synchronization problem between AZ and BAZ transmitters.
3. Aircraft antenna automatically switching to capture best signal, which could be front AZ overlap.
4. Aircraft fuselage obscuration of both fore and aft antennae momentarily.
5. Front AZ signal interference in the BAZ course area, causing interference.
6. Software interface problem between Bendix-King MLS 21 and Micronav ground equipment.
7. Software integrity difference between Bendix-King MLS 20 and MLS 21 (i.e. Bendix-King MLS 21 more sophisticated, therefore more sensitive).

It was decided that further flight tests were needed. The following were recommended to be conducted during these additional tests:

1. Install a Bendix-King MLS 21 in a DHC-6, due to lower cost of operating the Twin Otter.
2. Test with OCI antenna off to note flags.
3. Test with OCI antenna on to check that switching from front AZ to BAZ is not the source of the flag problem.
4. Test at various fuselage angles to obtain effect of antenna shadowing (if any).
5. If no flag problems experienced with the DHC-6, test DHC-7 after MLS installation is double checked.
6. If flagging problem persists, review all software and data work information related to back azimuth operation.

A flight test was conducted on October 13, 1987, in C-FJCL, to determine if the flagging experienced was only applicable to C-GXPO.

The Twin Otter was equipped with a Bendix-King MLS 20 and MLS 21 receiver, and installed to observe if both receivers were reacting similarly to the received MLS ground signal.

On the front course, both receivers provided identical correct information, and no deviations were observed. In the BAZ, however, the MLS 20 sought the strongest signal, and did switch from the BAZ signal to the AZ, depending on the location of the aircraft in the BAZ coverage area. Full deflection was observed, but no flags. On the other hand, the MLS 21 did track reasonably within the BAZ area, but flags were present. The panel annunciator light did go off on occasion, and subsequently, flags were observed. The flags would appear once for about every three times the light would go off on the annunciator. During runs east to west in the BAZ area, flags would appear once or twice each run. Six complete runs were made at altitudes varying between 3000 ft. ASL and 5000 ft. ASL.

The following was the course of action after the results of the test:

1. Conduct another test in a DHC-6, equipped with the two MLS receivers, but also an oscilloscope to provide more detail on the MLS signal being received.

2. Double check the MLS installation on C-GXPO, and operate a test flight with an oscilloscope. Video record the oscilloscope in order that test data can be reviewed by Bendix-King.

On October 8, 1987, C-FJCL was flown on a test flight with an oscilloscope installed on board the aircraft. An MLS 20 receiver was fitted on the Captain's side, and an MLS 21 receiver on the F/O's side. Each receiver was connected to dual fore and aft antennae. The MLS 21 was fitted with a test panel to permit AZ or BAZ selection and output points to receive log video on a portable oscilloscope. Raw video output could be displayed on the oscilloscope.

In the front AZ area, sharply defined amplitudes were evident on the oscilloscope. In the BAZ area, the oscilloscope displayed lower amplitude patterns. The pulses were not as well defined as the AZ signal, but considerably wider and "rougher" in outline. Several flights were conducted in the BAZ area at altitudes between 1500 ft. and 4500 ft. ASL. The oscilloscope trace remained very low in amplitude and rough on all the "runs" in the BAZ coverage area.

No Micronav technicians were available to switch off and on the front AZ during the flight test.

While no conclusions were reached as to the source of the flagging problem, it was recommended a thorough check be made of the BAZ transmitter to ensure the correct signal format was being transmitted. The siting of the BAZ antenna in relation to the missed approach path was also raised as a possible source of the problem, with respect to the strength of the BAZ signal.

A test was scheduled for C-GXPO on October 13, 1987. The test was in response to the course of action of the test flight results conducted a week earlier. This test flight had an oscilloscope installed. A Bendix-King representative and Micronav technician were on the flight as observers. The following summarizes the tests conducted on the flight:

### Test #1 - Full Approach/Missed Approach

MLS working correctly in the front course area. Flags experienced in BAZ area at 2.9 DME (4400 ft. ASL) and 4.4 DME (5900 ft. ASL). Descending east to west towards airport, numerous flags observed, particularly at lower altitudes at .5 NM east of airport.

### Test #2 - Full Approach/Missed Approach

No AZ problem, but four flags observed in the BAZ coverage area.

Test #3 - Front AZ Shut Off

No flags observed at an altitude of 3500 ft. ASL, west to east.

Test #4 - Front AZ On - Rear Antenna Off

Several flags observed on each to west run at 4500 ft. ASL.

Test #5 - Front AZ Off - Pear Antenna Off

No flags on Capt. indicator, but four on F/O's, in a west to east run at 4000 ft. ASL.

Test #6 - Front AZ Off - Front Antenna Off

Only one flag observed on F/O's indicator on an east to west run at 4000 ft. ASL.

Test #7 - Front AZ On - Both Antennae On

Numerous flags observed flying east to west at 3500 ft. ASL.

Test #8 - Front AZ On - Rear Antenna Off

Flags experienced on F/O's indicator on a run west to east at 3500 ft. ASL.

The oscilloscope could determine low quality MLS signals being received during the flight profiles in the BAZ coverage area. It confirmed that when the front AZ was off, the BAZ signal was good. Similarly, the oscilloscope showed that when one antenna was disconnected, the signal reception was better. There was also a correlation between the oscilloscope pattern, and when panel annunciator lights went off, and flag indications were observed.

It was suggested that an antenna switching problem could be causing the flagging problem. The MLS receiver software selects the strongest signal for antenna sensing, which is not necessarily the BAZ signal in the BAZ area. While the BAZ selector switch does indicate BAZ signal valid, it does not instruct the receiver/antenna to select only BAZ signal. The alternatives discussed by the technical team included changing the MLS 21 software to allow the antenna to seek only a BAZ signal, or to manually select the antenna to only receive the BAZ signal. It was concluded that Bendix would be requested to amend the MLS 21 software to seek BAZ signals in the BAZ coverage area. It was also agreed that Micronav and Bendix-King would exchange data on software interface to ensure compatibility between data word bit signals. Bendix-King agreed to make the suggested software changes, but cautioned that extensive software changes made, due to the uniqueness of the Pemberton approach, could restrict the application to those receivers used only for the Pemberton approach. Bendix-King also did not want to change the software structure to the point where a Technical Service Order (TSO) was required due to the changes to the receiver.

Upon completion of the software changes, and other recommendations of the previous flight tests, a flight test was flown on March 21, 1988. The purpose of this test was to try the new software for the MLS 21 receiver. The new software removed the natural bias of the receiver to seek the strongest signal in areas of signal ambiguity. Tests were conducted primarily in the BAZ coverage area.

C-FJCL was used for the test, and was equipped with a Bendix-King MLS 21, with the new software installed. The receiver was linked to the F/O's flight instrument display. A digital storage oscilloscope and video recorder were also used in the test. Inclement weather and a low cloud base and turbulence restricted the flight profiles which could be conducted. The BAZ transmitter had been shut off, and arrangements had to be made to turn on the equipment. A senior specialist on microwave landing systems, who had designed the software for Bendix-King, was on the test flight to observe and provide advice on the flagging problem.

The oscilloscope did not observe a BAZ signal during the test flight, but the MLS annunciator displayed a "Valid" MLS signal with no flag. The course deviation needle indicated a "fly right" deviation while on the 067° track. Several east-west flights were made in the BAZ coverage area, including flights directly in line with the BAZ station. An alternate MLS-21 was installed, and all connections and antennae were double checked. A field visit to the BAZ station was also made by the Bendix-King MLS specialist, to check the MLS transmitter. Tests conducted in the front AZ coverage area confirmed that the onboard equipment was functioning normally, and the oscilloscope indicated a good strong signal.

This test was different from the previous tests. On previous tests, an intermittent BAZ flag was observed, but the course deviation needle was centred on the desired track. On this test, no flags were observed but the course deviation needle was in error. The oscilloscope recorded no BAZ signal, therefore a flag should have been displayed.

It was recommended at the conclusion of this test that Transport Canada would be contacted to review the video recording of the Beechcraft King Air test conducted by Transport Canada. Bendix-King took a video recording of this test flight. Liaison would also be established between Bendix-King's specialist in data word and synchronization and a Micronav consultant. Micronav would also be asked to review reasons why the BAZ signal was not observed on the oscilloscope. A video tape of the oscilloscope pattern was retained by Bendix-King to review with other microwave specialists.

### 10.3 Results of Additional Testing

Approximately 15 hours of additional flight testing was conducted in an attempt to solve the BAZ flagging problem. Several hundred hours were spent in discussions with technical advisors, making software modifications, loading and unloading special equipment, making changes in MLS 21 receivers, ground station adaptations, and other efforts to discern the problem and correct it.

The additional testing did not resolve the problem, but it did help to identify the sources of the problem. The additional research during the Pemberton MLS/STOL program should prove beneficial for other future MLS installations with back azimuth equipment. It also led to a better understanding of the complexity of the ground station siting, and need for synchronized communication between each station. It also illustrated the importance of the interface between the airborne equipment manufacturer and the ground station manufacturer. The airborne and ground equipment has to operate as a unified system.

The next sub-section outlines the work tasks which will be required to solve the back azimuth flagging problem.

## 10.4 Work Tasks to Solve Problem

Based on the additional MLS tests using the experimental Bendix-King MLS 21 software, the following observations and a list of recommended work tasks were developed by the technical team attempting to solve the back azimuth problem.

### Observations

1. Experimental Bendix 21 software did improve the MLS signal reception by eliminating the normal bias to seek the AZ in periods of signal ambiguity. There were flags still experienced, however, in the BAZ coverage area.

2. Some multi-path signals observed on the log video, which could be from illuminating nearby Mount Currie. It could also be from reflections off the airport runway or rain showers.

3. Signal reception improved with OCI antenna turned on, but did not solve the problem.

4. No signal leakage was observed from a Micronav Bendix 20 test unit installed in automobile, and tests conducted near the MLS transmitters.

5. Location of BAZ site causes a good deal of the BAZ coverage problems (eg. not a normal BAZ site in location or function, which affects the required synchronization and software needed for this unique configuration).

6. Basic Dataword 7 transmission provides the guide to the MLS receiver to seek the BAZ signal, and the receiver had difficulty locating this signal identification code in coverage area, likely due to some multipath reflection. Test equipment onboard, however, did not permit a thorough analysis of the Basic Dataword 7 format to ascertain problem, but indications are that additional transmissions of Basic Dataword 7 would assist receiver to seek BAZ signal. (i.e. double transmission).

## Recommendations

A. **Micronav Tasks:**

1. Check alignment of OCI antenna to ensure the best possible line of sight coverage.
2. Add additional OCI antenna (eg. 2 - 3) to improve signal in BAZ coverage area.
3. Narrow the horn antenna installed at the BAZ site to reduce the horizontal sweep of the signal in order to eliminate possible multi-path error radiating off Mount Currie.
4. Check the downward tilt of the BAZ antenna. If it is too low, it could be illuminating the airport runway.
5. Loosen up the BAZ synchronization rate in order for the BAZ to operate independently from the AZ for a period of time without the BAZ automatically shutting down.
6. Install PROM software to increase the Basic Dataword 7 transmission by at least once a second (eg. double current rate of transmission). Additional transmissions will assist receiver in seeking BAZ signal. It is recognized that under the 1985 ICAO format, Basic Dataword 7 will change to Basic Dataword 5, but it is recommended that the software changes be made to Basic Dataword 7 now, and test the results of the change, rather than wait for the Canadian government to adopt the new format with Basic Dataword 5, and still not know if the problem is solved.

B. **Bendix Tasks:**

1. Provide PROM software for receiver, which will correlate with additional Basic Dataword 7 transmissions from ground station.
2. Check experimental software on Bendix 21 to ensure maximum advantages inherent to seek BAZ signal.

C. **AirBC Tasks:**

1. Install directional antennae on test aircraft (both front and back), located about 14" apart. Directional antennae can be directed at the BAZ signal to ensure better reception.

2. Seek test equipment which has the ability to monitor Basic Dataword 7 transmission on log video.

D. **Transport Canada:**

1. Continue to provide technical advice on possible solutions to solving problem.

2. Seek special test equipment which will allow a comprehensive analysis of problem. (eg. ability to discern Basic Dataword 7 format).

E. **Transportation Development Centre:**

1. Consideration of funding of test flights for research and development of BAZ signal coverage in non-standard configurations.

The responses received from the various interested parties to the recommended work tasks are summarized herein:

a. **Micronav Tasks**

- In response to Work Tasks 1, 2, and 3, Micronav will provide additional antennae and shall attempt several antenna configurations for OCI and back azimuth I/D.
- Work Task 4 - The BAZ antenna is tilted in a direction of 2.7° downward from the horizontal. It can be modified to the lowest point of coverage AirBC requires in the vertical plan.
- Work Task 5 - Micronav will modify the software to allow the BAZ to transmit for a short period in the event that it should lose synchronization from the azimuth antenna.
- Work Task 6 - Micronav will modify the software to increase the transmission of Basic Dataword 7.

b. Bendix-King Tasks

- Work Task 1 - Bendix-King will provide the PROM software for the receiver, which will correlate with the additional Basic Dataword 7 transmissions from the ground station. Bendix-King requires about six weeks of lead time prior to a flight test to make the software changes.
- Work Task 2 - Bendix-King has double checked the experimental software in the MLS 21.

c. AirBC Tasks

- Work Task 1 - AirBC will install directional antenna at time of next flight test.
- Work Task 2 - AirBC has discussed with Transport Canada the possibility of using Transport Canada test equipment.

d. Transport Canada

- Work Task 1 - Transport Canada has continued to provide technical advice and has agreed to provide ongoing cooperation.
- Work Task 2 - Transport Canada are exploring the possibility of scheduling their specially equipped DHC-8 aircraft to Pemberton in the Spring of 1989. This aircraft is equipped with test equipment to conduct a comprehensive analysis, including the ability to discern Basic Dataword 7 format.

e. Transportation Development Centre

- Work Task 1 - The TDC is exploring ways and means to provide funding for test flights for research and development purposes, as well as final flight certification tests. Both Micronav and AirBC have been requested to submit proposals to the TDC for funding consideration.

## 11. COMPARATIVE NAVIGATION SYSTEM RISK ANALYSIS

The Advisory Review Committee discussed in some detail whether or not there was a need for backup navigation systems to reduce the risk of an accident during an MLS/STOL approach into the Pemberton Airport. The installed MLS system, while a Private Class B installation, does have built-in redundancy similar to Transport Canada's own Class C standards. The NDB's are dual systems, as is the DME. The AZ/EL and BAZ are technically single transmitters, but do have dual components in a number of areas. The mean time between failure (MTBF) is also very high due to solid state technology and modular design of the components. All the ground stations also have a standby battery source of power should the main hydro electric or diesel electric generator fail.

On the advice of the Committee, the Transportation Development Centre agreed to conduct a separate study to assess the comparative navigation system risks at Pemberton Airport. The report would be used as a guide to determine necessity of redundant backup navigational systems. The TDC contracted Aviation Planning Services Ltd. of Montreal to conduct the risk analysis. A report was submitted in April, 1988, and should be referred to for details on how the analysis was conducted, and the specific results. The following summarizes the findings of the risk analysis report:

Two types of risks were analyzed. The first examined the probability of an aircraft being without adequate navigational guidance while conducting the approach/missed approach. The second examined the proximity of the aircraft to terrain (both laterally and vertically) while navigation guidance was available.

A number of Canadian and European airports were selected for comparison purposes. For each airport the following factors were considered:

1. Effective mean time between failures of navigation equipment.
2. Instrument procedures where segments of up to two navigational aids could constitute a hazardous condition.
3. Time which an aircraft would be dependent on navigation aids in the segments outlined above.
4. Probabilities of failure of one or two aids which would constitute a hazardous situation.

The analysis indicated that a hazardous situation (eg. absence of adequate navigational guidance) was most probably during the missed approach phases of flight. The comparable probabilities of this occurring at Pemberton in comparison to two other B.C. airports is as follows:

| | |
|---|---|
| Castlegar | 1.44 X $10^{-5}$ |
| Pemberton | 1.27 X $10^{-5}$ |
| Terrace | 2.09 X $10^{-10}$ |

In terms of the terrain clearance analysis, it was found that while Pemberton's lateral terrain clearances were less than Castlegar or Terrace, it compared quite favourably with European airports where conventional ILS or localizer only approaches are already authorized. The Pemberton approach, based on the tracking precision of MLS, should provide Pemberton with adequate lateral terrain clearance.

The vertical terrain clearance analysis indicated a potential problem only during one segment of the missed approach procedure. This was for a distance of 2 NM past the 6.4 DME turn point towards the Lillooet NDB. The report recommends a minimum altitude of 5300 ft. ASL at ISA +10 by the 6.4 DME turn point is needed in order to proceed to the Lillooet U6 NDB and cross at 6500 ft. ASL or higher. During the winter months, when 0°C. temperatures or lower prevail, climb performance is increased at least 80'/NM, which should lessen the perceived minimum altitude problem. Limiting the maximum landing weight of the aircraft may have to be in place when higher temperatures are experienced. The weight limitation does not impose an economic penalty to DHC-7 operations at Pemberton, due to the short sector distances between Pemberton and Vancouver or Seattle.

The report noted that the missed approach procedure was dependent on the dual NDB Lillooet U6 beacon. The failure of this station would leave an aircraft with no backup navigation system (radar could be used for a shuttle climb over Lillooet Lake to a safe enroute altitude). The report recommends that aircraft operating into Pemberton carry an independent onboard navigation system, such as Loran C. This independent airborne navigation system effectively improves the probability of being in a hazardous situation in all phases of the approach procedure, especially during the missed approach when navigational backup could be advantageous.

In conclusion, the report states that the Pemberton MLS/STOL approach procedure is sufficiently safe to allow Instrument Meteorological Condition (IMC) procedures, as described in the proposed charts and modified in the risk analysis study.

# 12. FINAL FLIGHT CHECK PROGRAM

In Chapter 5 the certification process was outlined. Certification of the Pemberton MLS/STOL system will allow Transport Canada to authorize the carrying of revenue passengers by AirBC in its MLS equipped DHC-7 aircraft.

It is evident that considerable progress has been made towards completing certification. Research and development experience of operating an aircraft using MLS and STOL technology has also been an accomplishment. The importance of developing a total system with coordinated inputs from the air service operator, MLS airborne and ground station manufacturers, regulatory/ airworthiness personnel, and Transport Canada's research and testing personnel, is also a recognized accomplishment. There are, however, some work tasks to be completed before final certification can be accomplished. This chapter discusses the remaining work tasks.

## 12.1 Back Azimuth Reception Tests

Chapter 9, Flight Test Program, indicated the problem of warning flags appearing in the back azimuth coverage area of the missed approach segment. Chapter 10 addressed the back azimuth problem in some detail. It outlined the work tasks to solve the problem. Some of these work tasks now have been accomplished. Further flight tests, however, are needed to test the system to ensure that the problem has been solved.

Depending on the availability of funding, a comprehensive flight test program has to be initiated, ideally in late February or early March, when VFR weather can be expected, but cold winter temperatures are still evident. This would provide an opportunity to flight test under conditions similar to actual operating conditions of a scheduled air service during the winter months. It would also allow an opportunity to analyze the effect of ice and snow on the ground equipment, and if changes occur on the MLS reception pattern due to snow reflection.

Micronav should be in the field one to two weeks in advance of the flight tests to make the necessary changes to improve BAZ reception, and to have the ground equipment ready for the flight tests.

Transport Canada is investigating scheduling their DHC-8 to Pemberton during this time frame, at the same time as a routine check of the Nanaimo MLS is being conducted. This DHC-8 has the necessary test equipment to investigate the BAZ reception, including the synchronization of Basic Dataword 7, which signifies a subsequent BAZ signal transmission to be received by the MLS receiver.

Based on the results and recommendations of the Transport Canada DHC-8 flight test, AirBC's C-GXPO would be flown in a test program to confirm that the BAZ reception had been solved. A two week program would be planned, but with the anticipation that only about 15 hours of actual flight time would be required. A successful completion of flight tests which solved the back azimuth problem would signify that the other certification steps can be now undertaken and completed.

## 12.2 Ground Equipment Certification

Micronav indicates that type certification of their ground equipment will be complete at the end of March, 1989. Type certification is needed before the Pemberton MLS installation can be finalized. Transport Canada has already inspected most of the Pemberton installation, but requires completion of all the components (eg. RF communication links, up-dated software, maintenance procedures, and remote monitoring), before the installation can be certified. A Transport Canada flight check with the DHC-8 will be required as part of this certification step.

## 12.3 Initial Transport Canada Flight Checks

As discussed in Chapter 5, a final airworthiness flight test will be needed. The initial Transport Canada flight check described in Chapter 9 detailed the tests which had been completed. Some deficiencies were noted in the earlier flight check, and the aircraft will have to undertake a final airworthiness check prior to certification of the MLS equipped DHC-7 to be used on the route service. The deficiencies are noted in Transport Canada's letter of August 27, 1987, and detailed in Chapter 5. Transport Canada has indicated that a one-week period would be required for the final airworthiness flight check. About 10 hours of actual flying would be required to complete the necessary tests.

## 12.4 On-Going Data Collection

The "Comparative Navigation System Risk Analysis" report noted the need for additional weather information. It also indicated the need for an independent airborne navigation system such as Loran C, as a backup navigation guidance system, particularly in the missed approach segment.

### Weather Data Collection

In May, 1988, Transport Canada began a contract to obtain Pemberton weather observations. An Atmospheric Environment Services (AES) weather station was installed at the Pemberton Airport some months earlier, along with the appropriate equipment. Weather observations are taken five times a day, between 8:00 a.m. and noon. These observations are entered into the AES communication system. Weather observations include standard aeronautical observations, including ceiling and visibility. Nearly a year's records of weather observation will be available in the Spring of 1989, when final certification will be approved by Transport Canada.

### Loran C Monitoring

Loran C monitors had been installed at Pemberton Airport by the U.S. Coast Guard and Megapulse. A limited amount of data was collected and analyzed. The data collected indicated that the Loran C signal generally is excellent, and a Loran C airport monitor system would provide reliable data to permit non-precision approaches to the Pemberton Airport. Table F summarizes the Loran data.

The Loran analysis noted the average error recorded was 21.6 ft., with a standard deviation of 16.4 ft. In this case, it would take a circle with a radius of 95 ft. to enclose the data points. Two error factors were noted. One was the low SNR of the signal from George, WA, and the other was the short time constant. It was also noted on certain nights between 12:00 midnight and 6:00 a.m., the SNR, particularly from George, fluctuated considerably. This could have been the result of B.C. Hydro and Power Authority shuttling electric power over a nearby 500 KVa transmission line between the interior of the province and the Vancouver mainland.

Transport Canada conducted airborne tests of Loran C reception in the Pemberton Valley. These tests indicated excellent reception with a steady signal throughout their flight tests.

**Table F**
**Loran-C Data**

| | Williams Lk. | Pr. George | Pt. Hardy |
|---|---|---|---|
| TD | - | 29715.58 USec | 42743.01 USec |
| SNR | + 11 dB | + 8 dB | + 10 dB |
| Field Strength | 82 d Bu | 64 d Bu | 67 d Bu |
| ECD | + 2.5 USec | + 1.7 USec | + 0.9 USec |
| Dist./Receiver | 187 km. | 423 km. | 329 km. |

AirBC equipped C-GXPO with an ANI 7000 Loran receiver. Loran C signal was generally good throughout the Pemberton Valley. At low altitudes, however, over the Missed Approach Point (MAP) the Loran signal frequently disappeared. Changes of Loran receivers and antennae did improve the Loran reception, but problems continued to be experienced. It was concluded that B.C. Hydro and Power Authority transmission lines which cross the Pemberton Valley in the vicinity of the MAP could be the source of interference. ANI recommended the Loran antenna be repositioned from the belly fuselage area to the top of the aircraft. This would shield the antenna from the probable source of ground interference. It would also eliminate moisture from accumulating at the antenna connector, which was the case with the under-hull installation. Because the DHC-7 does not have an antenna plate on the top of the fuselage, and the resultant need to enter the pressurized hull of the aircraft, the relocation was not done during the current research project.

Additional Loran C research will have to be conducted if Loran C is to be the independent airborne navigation system recommended in the risk analysis report. An on-going Loran monitoring program will be needed to ensure that Loran signals are acceptable for navigation purposes in the Pemberton Valley when the DHC-7 conducts an instrument approach. Loran C, however, may not be a condition of final certification by Transport Canada, but it is a recommendation of the "Comparative Navigation System Risk Analysis".

# 13. CONCLUSIONS OF RESEARCH

Conclusions can be reached as to the findings of the Pemberton MLS/STOL Flight Demonstration Project. These conclusions are based on the various research activities undertaken to date. There may be some modifications to these conclusions during the final certification flight tests. This chapter discusses these conclusions.

## 13.1 Flight Procedure Evaluation

The Pemberton MLS approach procedure is unique. The mountain valley approach combines MLS technology with STOL aircraft characteristics to allow an instrument approach into landing areas which previously had been impossible with conventional ILS precision approaches. The MLS precision tracking and the STOL aircraft's ability to conduct steep approach and climb gradients, provides the necessary terrain clearance to allow scheduled flight operations. The Pemberton approach is also unique, in that it is not a straight-in approach/missed approach. It requires a turn from the front azimuth to line up with the back azimuth. The back azimuth sector also requires a climbing turn as part of the missed approach/departure procedure.

The flight procedure evaluation flight tests indicated that the approach chart procedure for Pemberton is a valid approach procedure with sufficient terrain clearance to meet Transport Canada's safety criteria. Only minor modifications were required from the original design of the approach chart and flight procedures developed in the early 1980's.

## 13.2 Aircraft Flight Characteristics

The MLS/STOL flight tests with the deHavilland DHC-7 STOL aircraft concluded that the aircraft has superior flight characteristics. Under all normal, abnormal, and emergency procedures, the aircraft accomplished all the performance criteria needed to conduct the MLS/STOL approach. The aircraft's ease of handling and flight characteristics resulted in good flight crew coordination, despite the relatively complex approach procedure. One engine inoperative did not deter the aircraft performance below acceptable Transport Canada's requirements, or the climb gradients required in the missed approach/departure segments of the approach procedure.

## 13.3 Airborne Receivers

The dual Bendix-King MLS 21 receivers provided the desired azimuth tracking and glideslope guidance necessary for the approach and missed approach. Changes were made to the software to resolve the back azimuth flagging problem, but more testing is required to ascertain its success. The two antennae located fore and aft appear to provide the MLS reception required with no shadow effects from the aircraft's fuselage. The control head for the MLS receivers is convenient and information is easy to read. A change to ICAO 1985 format will allow a magnetic track readout, which is preferred due to the complexity of the approach. The existing ICAO 1981 format had a readout left or right of 0° (desired track). The panel annunciator lighting system is confusing to the flight crew, and will be modified by AirBC prior to the final flight tests.

## 13.4 Ground MLS Equipment

The Micronav MLS ground equipment provides a good signal in all areas of coverage. The front azimuth signal is a superior signal throughout the coverage area. No flags were experienced in any tests in the front coverage area. The back azimuth coverage area does have a weaker signal, and flags have been experienced. It would appear that a number of minor problems contribute to the flagging problem, which are not necessarily only linked to the back azimuth transmitter. These other problems include an overlap of the front azimuth signal in the back azimuth coverage area, synchronization of signals between the front and back azimuth stations, and Basic Dataword 7 software, which time-sequences the signal to indicate that a back azimuth signal will be transmitted. Chapter 10 detailed the work tasks needed to correct the back azimuth flagging problem.

NDB reception for both the Pemberton T6 NDB and the Lillooet U6 NDB is good, and well located for navigation guidance.

The DME is a conventional DME, but provides suitability accuracy for the MLS approach. A DME-P may be required when precision DME is available. The Micronav MLS can accept DME/P.

The MLS equipment maintenance needs have not been determined since the equipment, particularly the diesel operated stations, was only operated during the flight tests. The equipment should be left operating for a longer period of time to ascertain its reliability and maintenance needs. AirBC, as a potential air service operator, has some concerns as to the ongoing MLS maintenance program, and who the agency will be which will have ongoing responsibility to ensure the system is operating to Transport Canada standards.

### 13.5 Meeting Project Objective

As noted in Chapter 1, the objective of the technical research program was to determine the feasibility of the DHC-7 to meet Transport Canada criteria for the use of an MLS instrument approach/missed approach in the Pemberton Valley. The Pemberton MLS/STOL Flight Demonstration Project did accomplish this objective. The program did develop the expertise techniques and equipment in MLS/STOL technology. The project did demonstrate flight profiles, integrated flight procedures, and did test the application of MLS and STOL technologies under difficult operational conditions in mountainous terrain.

A secondary objective, however, was not met. Transport Canada certification of AirBC to use suitably equipped DHC-7 aircraft under instrument conditions at Pemberton was the second objective of the research program. While significant progress has been made towards certification, it was not obtained. There are still some work tasks to be done, principally solving the back azimuth flagging problem. Certification, however, is an achievable goal.

# 14. **RECOMMENDATIONS**

Throughout this technical report, a number of recommendations have been made to assist future research projects of a similar nature. There are, however, two principle recommendations to ensure that the efforts made in the Pemberton MLS/STOL Flight Demonstration Project will continue and that a significant contribution can be made to Canadian MLS/STOL achievements.

## 14.1 Further Testing

The MLS/STOL Flight Demonstration Project did achieve its principle objective with the flight program. Transport Canada certification, however, was not achieved, due to minor technical difficulties. It is recommended that further flight testing be conducted. The flight tests would be to solve the back azimuth flagging problem, and for the final Transport Canada certification flight test. Details are noted in Chapter 5 and 10 of the report as to the need for additional flight tests. Approximately 15 hours of flight time would be required for the back azimuth research flying, and a further 10 hours of flight time for the final flight test by Transport Canada Airworthiness.

## 14.2 On-Going Coordination

It is apparent that the Pemberton MLS/STOL Flight Demonstration Project created a significant amount of interest from the aviation industry around the world. The application of MLS/STOL technology for instrument approaches in mountainous valleys is of great interest to a number of countries where conventional precision approaches are not possible.

The Advisory Review Committee established for the Pemberton MLS/STOL Flight Demonstration Project has worked as a coordinated team to address and solve the problems as they arose during the program. Coordination between AirBC, Bendix-King, Micronav, Transport Canada, and Transportation Development Centre, has been readily demonstrated, and this coordination has been effective in achieving the project's principle objective. It is recommended that on-going coordination is still needed to ensure that the second objective of certification is achieved. With final certification, Canada will have the MLS/STOL technology to demonstrate to other countries which require instrument approaches in mountain valleys to improve air service. It will have also provided a much needed air service to the Village of Pemberton and the Resort Municipality of Whistler, which has not been possible using conventional technology.

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# APPENDIX A
## ADVISORY REVIEW COMMITTEE - OBJECTIVES & RESPONSIBILITIES

(AS AT MARCH 31, 1987)

### OBJECTIVES

#### Overall Objective

Daytime IFR Service to Pemberton with limits:

| | |
|---|---|
| Decision Height | 1000 ft. AGL |
| Visibility (RVR) | 1.5 miles |

using MLS Approach Criteria for a 7.7° glideslope and in accordance with FAA Order 8260.30 (Appendix IV).

#### Project Objective

Subject to the overall objective targets

1) Establish Flight profile and procedures for

    a. approach
    b. departure
    c. missed approach

2) Test and verify that equipment and procedures can safely demonstrate Canadian MLS & STOL technologies.

## PARTICIPANTS

- Transportation Development Centre (TDC)
- AirBC
  Flight Operations Avionics
  Administration
- Pacific Avionics/DAR
- Test Support
- Bendix
- Micronav
- deHavilland
- Village of Pemberton (Weather)
- Department of Transportation & Highways, Province of B.C.
- Transport Canada - Pacific Region
  Air Navigation Requirements
  Telecom
  Air Carrier
  Air Traffic Services
  Airworthiness Engineering
- Transport Canada - Ottawa
  MLS Project
  Air Navigation Requirements
  FESD
  Airworthiness Flight Test
  Air Carrier
- Atmospheric Environment Service (AES)3.a

## GROUND EQUIPMENT LIST

| MLS system | I.D. |
|---|---|
| Front Azimuth & Elevation | AZ1 & EL |
| Missed Approach Azimuth | AZ2 |
| Distance Measurement Equipment | DME |
| Non- directional Beacon Pemberton | NDB1 |
| Non-directional Beacon Lake Lillooet | NDB2 |

Weather Instruments
- Ceiling
- Visibility
- Precipitation
- Temperature
- Wind

Communications

Daytime Lighting
- Recommended VASIs or PAPIs

## GROUND EQUIPMENT ACTIVITIES

| Item | Responsibility |
|---|---|
| Equipment Operating for Flight Tests | Micronav |
| Equipment at Site (Final) | Micronav |
| System Operational | Micronav |
| Calibration of Signal at Site (Final) (20 hours of A100*) | MLS Project |
| Certification (Lab) | FESD - Headquarters |
| Risk Analysis (if required) (Operations) | (Operations) |
| Proof of Performance | Micronav |
| Commissioning Flight Check | ANS Region |
| Facility Operating Manual | Micronav |
| Commissioning of Facility | ANS Region |

* Additional KingAir and/or DHC-8 flying on basis of Cost Recovery building confidence withy use over time.

## AIRBORNE EQUIPMENT ACTIVITIES

| Item | Responsibility |
|---|---|
| AirBC development program (with DH Test Data Support) | DH/AirBC/DAR |
| Engineering submission to TC | DAR |
| Flight Manual Supplement | Air Carrier |
| TC airworthiness evaluation<br>Engineering<br>Flight test | Airworthiness |
| Modification approval | Airworthiness |

### Suggested Minimum Requirement

- Dual Systems
  - MLS
  - HSI
- Flight Director Integration
- Data displayed on HSI
- GPWS - Compatibility
  - Integration

also desirable:
- Status display for missed approach azimuth
- Autopilot coupling
- Azimuth Switching (Automatic?)

## FLIGHT OPERATIONAL REQUIREMENTS

| Item | Responsibility |
|---|---|
| Company Route Approval Submission | AirBC |
| Company Approach Approval Submission | AirBC |
| Technical Flight Program (Aircraft Capability) | AirBC |
| Flight Manual Supplement (Technical) | DH/AirBC |
| Flight Program Implementation (55 hours) | AirBC |
| Pilot Training Requirements<br>Procedures Evaluation | |
| Operations Manual Approval | Air Carrier Region |
| Training Program Approval | Air Carrier Region |
| Operations Certification Addendum (Company Approach and Route Approvals) | Air Carrier HQ |
| Build Confidence | AirBC |

**Recommendation:**

Define Special Requirements for approach
e.g. beacons/lights on approach
switches/flags in cockpit

## CRITERIA AND APPROACH APPROVALS (TECHNICAL)

| Item | Responsibility |
|---|---|
| Approach Plate Preparation (based on 8260.30) | DH/AirBC |
| Approach Plate Submission | AirBC |
| Approach Plate Approval | Air Carrier |
| DHC-7 IFR Approach from 7.5° with 2° tolerance testing & approval submission | DH/London STOL Project |
| DHC-7 IFR Approach from 7.5° approval | Airworthiness |
| DHC-7 IFR Approach from 7.7° with 1.8° tolerance approval submission | DH/AirBC |
| DHC-7 IFR Approach from 7.7° with 1.8° tolerance approval | Airworthiness |

## DATA COLLECTION

- Position in Space
  - Horizontal
    - Del Norte
    - Loran
  - Vertical
    - Altimeter

- Signals on Board
  - Video Camera
    - Tracking HSI & Pilot Activities
  - FDAU
    - To track aircraft height/altitude
  - FDAU
    - To track Loran position
  - Log Video Recorder
    - For MLS (Bendix) Signal Reception
- Calibration Flights for DHC-7 (using King Air)
  - Suggested Constant Altitude segments through MLS Signal Field

# APPENDIX B
# FLIGHT TEST PROGRAM

## Initial Flight Tests

About 15 hours of flight testing was conducted in the initial flight test program. This initial flight test program was designed to confirm basic MLS signal reception and to develop a flight profile for future tests. Some flight failure modes were also simulated in the initial test period.

The first flight test conducted under the program was on March 22, 1987. The test was conducted on C-FIOH, a DHC-6 aircraft. The 1.5 hour test flight was conducted on behalf of Micronav to test front azimuth reception at various altitudes, particularly low altitudes close to in the AZ station.

A second flight conducted on March 30th, with the same aircraft, was designed to introduce members of the Advisory Review Committee to the Pemberton MLS approach, and was a reconnaissance flight. It included representatives of the TDC, Transport Canada (MLS Program, Airworthiness (Ottawa), Air Regulations), deHavilland, and AirBC. The 1.9 hour flight demonstrated signal reception and conducted a 7.7° angle of approach and missed approach procedure. It also demonstrated a departure approach.

The third flight test, on April 3, 1987, was the first to be conducted with C-GXPO, the test DHC-7. This flight was an intensive 2.4 hour test session. It included an RNAV approach to Pemberton, as well as identifying and tracking all ground stations. MLS front and back azimuth procedures were also tested. Departures off Runway 24 were conducted to confirm IFR departure procedures.

The April 8th flight test with C-FIOH was primarily to check the BAZ with Micronav technicians, but it also included verifying and tracking of NDB #1, approaches at 7.7°, missed approaches, and low level interception of MLS signals.

The April 13th test flight was conducted with C-GXPO. This flight test was conducted primarily to fly the extreme perimeters of the flight profile envelope. Emergency conditions were simulated, as well as signal re-capture from non-standard flight manoeuvres.

The test on April 15th was conducted with C-FJCL, the second DHC-6 (Twin Otter) with MLS receivers. This test flight had Transport Canada Airworthiness and Provincial Government observers. This test demonstrated the entire approach, departure/missed approach to the observers. The test also demonstrated the signal coverage in the front and back course areas.

These initial flight tests confirmed that navigation aid reception for the NDB's, DME, and the MLS transmitters throughout the Pemberton Valley was good.

> Pemberton (T6) NDB #1 reception was identified enroute on V321 at GABAL intersection, approximately 20 NM south of the station. Reception was good throughout the approach/missed approach segments for the dual 25 watt transmitter. Similarly, Lillooet NDB (U6) #2 reception was received throughout the entire procedure, including enroute on V349 nearly as far south as GARRE intersection, some 25 NM away. This NDB is also a dual 25 watt transmitter.

> The AZ, EL, and DME reception are all line-of-sight dependent, and reception was good throughout the design coverage area, this included the lower altitudes along the valley.

> The flight profile evaluation indicated that the STOL capabilities of the DHC-7 could easily handle the design flight profile. Slight variations to the design flight profile were conducted to confirm the safe parameters of the flight profile selected. The selected profile demonstrated adequate terrain clearances in all phases of the flight profile.

> Emergency procedures simulated during the approach/missed approach indicated no unusual flight characteristics.

## Main Flight Test Evaluation

The main flight tests were conducted between April 17th and July 28th, when about 45 hours of flight testing were conducted on C-GXPO. Most of the tests were conducted in July. These flight tests were conducted with the research equipment installed on the aircraft, as well as the MLS and Loran C receivers. Each test flight was about four hours in duration in flight time.

Flight test notes were taken for each flight, detailing the general observations, tests conducted, test results, and recommendations for subsequent testing. Each approach and departure/missed approach was numbered for the test day in order that flight notes, video tapes, and flight data recorder information could be cross checked. Flight comments were also recorded on the video tape, as were visual test numbers for subsequent reference. Turning off and on the third position VHF observer microphone was used as a test reference for recording data on the Flight Data Acquisition Unit (FDAU). The on/off switch on the microphone provides a discrete signal to the FDAU. The following summarizes the results of the flight tests which were conducted:

## > Enroute - Arrival

The IFR minimum enroute altitude (MEA) on V321 is 14,000 ft. between Victoria and Pemberton. The minimum obstruction clearance altitude (MOCA) is 10,800 ft. between Victoria and GABAL, and 11,600 ft. north of GABAL. VFR tests indicate that RNAV, using the Victoria VOR, receives a solid signal at flight levels above 12,500 ft. during the enroute portion. RNAV reception is intermittent below 10,000 ft. As noted, Pemberton NDB #1 reception can be identified in the vicinity of GABAL. This is a low power, 25 watt dual beacon transmitter. MLS "Valid" DME readout and identification of Lillooet NDB #2 are received at about 10 NM south of NDB #1.

The "Descent Check" from the Check List is conducted passing overhead the Pemberton NDB #1 on the outbound segment proceeding towards the procedure turn. The check also includes the setting up of the navigation aids for the approach as follows:

- NDB #T6 363 receiver on Capt. and F/O ADF's.
- MLS MIAB CH 600 receiver on Capt. and F/O controller set at 7.7°.
- MLS Panel Annunciator light indication correct.
- AZ and EL flags removed on Capt. and F/O HSI/CDI.
- Check DME readout on Capt. and F/O indicators.

Tracking outbound using MLS azimuth signal guidance, and a bearing from NDB #1 (T6), allows the pilot to confirm any wind drift with regard to direction and speed. Glideslope indication is also present as the aircraft passes through the elevation signal. Flight controls and navigation aids are set up during the outbound segment, descending to the procedure turn altitude of 9500 ft. The procedure turn to the northeast is executed at about 11.0 DME miles.

The procedure turn at 9500 ft. provides adequate terrain clearance. The MLS azimuth guidance allows for a predictable, smooth interception and tracking to the inbound course. Interception starts at about 16 DME, after completing the procedure turn. Manoeuvres are conducted at an indicated airspeed of 140-150 kts.

## > Approach

Inbound at 9500 ft., and stabilized on the selected AZ heading of 121°, the MLS elevation is intercepted at 10 DME. At the interception of the glideslope, the "Before Landing Check" from the Check List is conducted, including power settings (propeller RPM 1200, torque 400 lbs.), gear down, and flaps 25°. The aircraft is stabilized on the AZ and EL signals, using the HSI. The aircraft descends at about 1500 ft. a minute, and an airspeed of 100-110 kts., when established on the 7.7° glideslope. Flaps 25° is recommended for normal approach, but is a strong tailwind is experienced during descent, 45° flap may be required. If 45° flap is selected and power applied for a missed approach, flaps will automatically revert back to 25°.

At 6.0 DME, the FAF is reached (i.e. 6000 ft. ASL), the F/O monitors the BAZ signal, and sets up the required navigation aids for a possible missed approach. The setup includes the following procedures:

- NDB #1 T6 363 receiver remains on Capt.'s ADF.
- NDB #2 U6 390 receiver on F/O's ADF.
- BAZ MIAB checked to confirm operation if Capt. selects go-around.
- The aircraft continues to descend on the AZ and EL reference, with the F/O calling out the altitude, until the Missed Approach Point (MAP) is reached. The MAP is located at the Pemberton NDB #1, and is 1.1 DME from the AZ/EL station. The minimum descent altitude is 1600 ft. (930 ft. above ground).

- Upon visual sighting of the Pemberton Airport, the aircraft turns to a heading of 103°, and proceeds 2.1 NM from the MAP, and executes a landing at the airport on Runway 08. If a circling approach is required due to wind direction, etc., the ceiling height is increased to 2400 ft. (1730 ft. above ground). All circling is conducted north of the Runway 06-24 centerline. "After Landing" and "Shut Down" checks conducted by F/O.

> Departure

"Start", "Taxi", and "Line-up" checks performed by F/O. A visual climb is made to 1600 ft. (930' above ground), and the aircraft manoeuvres visually to intercept the BAZ track 067° west of the airport. Interception west of the airport is required to provide sufficient airspace for the required climb gradient should an engine be inoperative (OEI). Once established on the BAZ track, the aircraft climbs and follows the missed approach instructions outlined below from the point of interception. "After Take-off" check is conducted by the F/O.

> Missed Approach

At the MAP, the F/O signals that the MAP is reached, and the aircraft is at minima. If the airport is not visual at this point, the Capt. selects the "go around" button on the control yoke. This action automatically selects the BAZ on the MLS receivers and the flight control instruments. At the same time, gear is selected up and flaps are retracted to 15°. Climb power is set to maintain 1.25 Vs, or about 120 kts. "After Take-Off Check" items from the Check List are accomplished by the F/O. The Capt., using the pre-selected heading bug on the CDI for reference, turns the aircraft to an immediate climbing left turn on a heading of 090° to intercept the BAZ track of 067°. Capt. then selects Lillooet NDB #2 U6 390 on ADF. Once established on the 067° track, the aircraft continues to climb to a minimum altitude of 4040 ft., and a maximum altitude of 6200 ft. before reaching 6.4 DME.[1] The climb gradient needed to meet the altitude requirements to 6.4 DME is 460 ft./NM. Tests revealed the aircraft was usually at the 6,200 ft. altitude by 6.4 DME, and even well above the 4,040 ft. altitude with an engine inoperative. At 6.4 DME, an immediate climbing right turn is made to track to 109° to NDB #2 (Lillooet). A minimum altitude of 6500 ft. is required upon reaching the second beacon. At NDB #2, a climbing right turn is made to a track of 161°. The aircraft continues to climb to an altitude of 10,000 ft. from the Lillooet NDB (within 9 NM). A shuttle climb can be made to reach enroute altitude, but caution is required due to possible wind drift. Onboard weather radar and Loran C can assist navigation if a shuttle climb is needed, using the Lillooet NDB and the shuttle climb fix. Contact Vancouver Centre and advise. A right turn to the Pemberton NDB #1, and the climb continues to 12,000 ft. A climb gradient of 368 ft./NM is required after 6.4 DME.

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[1] Maximum altitude restriction is required to remain in BAZ coverage area.

The flight evaluation tests revealed no significant problems with the Pemberton MLS/STOL instrument approach. The DHC-7 aircraft handled the steep approach under all conditions. Tests were accomplished using flaps 0°, 15°, 25°, and 45°, with no difficulty, however, 25° flap is recommended as an approach standard. Approaches using up to 9.7° glideslope were accomplished with no unusual aircraft characteristics. Manoeuvrability of the aircraft to recapture the AZ and EL from unusual positions was easily recoverable. Simulated full payload weights were also no problem, even when weight was distributed out of the C of G limits of the aircraft. One engine out (i.e. 0 thrust) conditions were handled well by the aircraft, including the critical climb gradient performance needed on the missed approach segment of the flight path. The slow approach speed of the DHC-7 in the landing configuration, and the excellent forward visibility of the aircraft provided confidence in performing close-in circling manoeuvres in the narrow Pemberton Valley. MLS signal coverage and reception in the front AZ area was excellent. The BAZ reception, however, did experience problems.

## Initial Transport Canada Flight Tests

Transport Canada, Airworthiness, Ottawa, conducted a series of initial flight test evaluations during the week of July 27, 1987. Weather conditions and a lightning-damaged BAZ synchronization transmitter chip necessitated that three test flights be conducted over a week-long period. One test flight was conducted using the Nanaimo MLS facility (eg. signal/range reception). The following outlines the test performed:

## Flight #1 - MLS 21 Installation (conducted using FAA interim criteria dated April 28, 1986)

1. Check controls and displays for accessibility and unobstructed view.

2. Check displays in all ambient lighting conditions, including night.

3. Selecting between 0° and 25° flap, and cycling the landing gear, check operation of equipment is not adversely affected by normal aircraft manoeuvring.

4. Selecting between 0° and 15° flap, and cycling the landing gear, check that there is no interference with equipment resulting from:

   - VHF operation
   - ADF operation
   - weather radar
   - windshield heat
   - side window heat
   - elevator horn heat
   - propeller heat
   - interior lighting
   - exterior lighting
   - DC generator off/on
   - AC generator off/on
   - TRV Circuit pull/reset
   - batteries off/on
   - invertors off/on
   - lateral trim
   - directional trim

5. Selecting 0° - 25° flap, and cycling the landing gear, verify control head operation, including:

   - TST
   - Channel
   - AUTO
   - MAN selection
     - azimuth
     - glideslope
     - back azimuth

6. At an altitude of 3500 ft. AGL, selecting 0° - 25° flap and cycling the landing gear, conduct the following tests:

   - Starting at a range of approx. 50 NM, fly towards the MLS facility.
   - Confirm azimuth and elevation warning displayed.
   - Continue inbound and determine range.
   - Azimuth warning removed.
   - Glideslope warning removed.
   - Turn outbound and determine range.
   - Glideslope warning appears.
   - Azimuth warning appears.

7. At an altitude of 3500 ft. AGL, an Indicated Air Speed (IAS) of 110 kts., 25° flap, and the landing gear down, conduct the following test:

   At a range of 30 NM, fly 360° circle, starting from inbound heading.

   30° bank to Inbound (IB) + 60°
   15° bank to IB + 90°
   10° bank to IB + 270°
   15° bank to IB + 300°
   30° bank to IB + 360°

   Verify no warnings present.

8. At an altitude of 3500 ft. AGL, IAS 110, 25° flap, and gear down, conduct the following test:

   - At a range of 30 NM:

     a. intercept at 50° to Inbound Course

     b. repeat from other side

   Verify transition from clearance to guidance.

- At a range of 10 NM:

  a. fly aircraft to full course needle deviation

  b. repeat to other side.

  Verify correct deviation indicator.

9. At an altitude of 3500 ft. AGL, Vref speed, 25° flap, and gear down, and in level flight, fly through selected glideslope intercept point. Verify full up to full down deviations.

10. At Vref speed, 25° flap, landing gear down, and while tracking selected glideslope, manoeuvre aircraft through normal pitch and roll attitudes to full scale deviation above and below indicator. Verify no flags present.

11. At a 2000 ft. intercept, Vref speed, 25° flap, and landing gear down, carry out complete MLS approach with Inbound Azimuth intercept angle of 45° at approximately 12 DME. Verify no flags present and correct station identification.

Flight #2 - Steep Approach - Special Considerations
(tests conducted at heavy gross weight, forward C of G)

1. Starting at an altitude of 10,000 ft. AGL and continuing to 1000 ft. AGL, at Vapp speed, 25° flap, landing gear down, conduct a 7.7° approach.

   - Carry out WVT to +- 40° bank or SW.

   - At 1000 ft. AGL, using Vcl speed (1.3 Vs) app flap (25°), gear down, and Maximum Take-off (MTO) power, carry out at go-around to all engines operating (AEO), missed approach climb.

2. Starting at an altitude of 10,000 ft. AGL, and continuing to 1000 ft. AGL, at Vapp speed , app flap (25°), landing gear down, conduct a 9.7° approach.

   - At 3000 ft. AGL, reduce Eng. #1 to zero thrust and carry on approach.

   - At 1000 ft. AGL, Vcl speed (1.3 Vs), flaps select (15°), landing gear up, and MTO power, carry out go around to one engine inoperative (OEI), missed approach climb.

3. Starting at an altitude of 10,000 ft. AGL, and continuing to 1000 ft. AGL, at Vapp speed, flaps app (25°), landing gear down, conduct a 5.7° approach.

   - At 1000 ft. AGL, Vapp to Vcl speed, flaps app to select (15°), gear from down to up, carry out go around and simultaneously reduce Eng. #4 to zero thrust.

4. Starting at an altitude of 10,000 ft. AGL, and continuing to 1000 ft. AGL, at Vref speed + 10 kts., flaps app (25°), landing gear down, conduct a 7.7° approach with higher approach speed.

   - At 1000 ft. AGL, Vref speed, flaps 45°, gear down, complete transition to landing configuration and carry out normal landing.

5. Starting at an altitude of 10,000 ft. AGL, and continuing to 1000 ft. AGL, at V ref speed - 5 kts., flap app, landing gear down, conduct a 7.7° approach using the lower approach speed.

   - At 1000 ft. AGL, Vref speed, flaps 45°, gear down, complete transition to landing configuration and carry out normal landing.

Flight #3 - MLS Steep Approaches at Pemberton
(tests conducted at medium gross weight, aft C of G)

1. Selecting 0° and 25° flap and cycling landing gear up and down, confirm that with MLS selected:

   a. no flight director engaged in NAV or ILS mode

   b. autopilot can't be engaged in NAV or ILS mode

2. Confirm correct MLS audio identification.

3. At an altitude of 9500 ft. AGL, 140 kt. IAS, 0° flap, landing gear up, and PFLF (power for level flight) power, carry out procedure turn within 15 NM of the Pemberton T6 NDB:

a. confirm continued DME, NDB coverage.

b. confirm adequate MLS coverage.

4. Starting at an altitude of 9500 ft. ASL, and continuing to 1600 ft. ASL, 110 kt. IAS, flap 15°, landing gear up, PFLF power, intercept azimuth. Confirm valid BAZ annunciation:

   - at Vref speed, flaps 25°, landing gear down, intercept elevation.

   - during approach, confirm AL and EL deviation pointer guidance.

   - At 1000 AGL Vcl speed, flaps 15°, landing gear up, MTO power, carry out missed approach.

     Confirm correct MLS azimuth course. Confirm correct AZ deviation pointer guidance.

   - Climb to 6500 ft. AGL, Vcl speed, flaps 15°, landing gear up.

     Confirm continued DME and MLS coverage to 6.4 DME. Confirm Lillooet NDB coverage prior to 6.4 DME.

   - Climb to 9500 ft. AGL, 140 IAS, flaps 0°, landing gear up, complete missed approach and return to Pemberton NDB.

5. MLS Approach and Overshoot:

Starting at 9500 ft. ASL, 140 IAS, flaps 0°, landing gear up, PFLF power, switch off ground BAZ transmitter. Confirm loss of BAZ valid (switch back on ground BAZ after test).

- At 9500 ft. ASL, Vref speed, flaps 25o, landing gear down, intercept azimuth and elevation.

- During descent, fly off azimuth and elevation by 2 dots. Assess recapture.

- At 1600 ft. ASL, Vref speed, slaps 45°, gear down, complete transition to landing configuration and land.

6. Take-off and Instrument Departure:

Starting at ground, flaps 15°, take-off and climb to 9500 ft. ASL. Confirm satisfactory BAZ intercept, MLS, DME, and NDB coverage during departure.

7. MLS Approach and Landing with Electrical Failure:

Starting at an altitude of 9500 ft. ASL, IAS 140 kts., flaps 0°, PFLF power, intercept azimuth and elevation.

- During top of descent, Vref speed, flaps 25°, landing gear down, switch off AC generator #3, DC generator #2 (MMEL criteria).
- At 5000 ft. ASL in descent, cut Eng. #4 to zero thrust, and switch off AC generator #4, DC generator #4.
- At 1600 ft. ASL, Vref speed, flaps 45°, landing gear down, complete transition to landing configuration and land.

Reset generators.

8. Take-off and Instrument Departure:

AC generator #2 and DC generator #4 off (MMEL)

- Take-off, flaps 15°, MTO power, carry out normal take-off and instrument departure.
- At 2000 ft. ASL, Venr speed, flaps 0°, gear up, cut Eng. #1 to zero thrust and switch off AC generator #1 and DC generator #1.
- Continue to climb to 9500 ft. ASL, Venr speed, flaps 0°, landing gear up, complete OEI instrument departure.

Reset generators.

9. Electrical Failure Tests:

Starting at 9500 ft. ASL and descending to 1600 ft. ASL, Vref speed, flaps 25°, landing gear down, during the MLS approach pull and reset the following circuit breakers and note annunciations:

a. LHS MLS-21 CDU

b. RHS MLS-21 CDU

c. MLS Annunciator Panel

d. Any other MLS CB.

The Transport Canada debriefing session at the completion of the initial flight tests noted the following observations and recommendations:

1. MLS station identification check indicated only 3 of 4 letters transmitted (i.e. letter B missing from "MIAB".

2. Approach #1 - flap 15°, props 1200 RPM - Normal approach as per approach plate carried out, and AZ and EL responses were no problem to intercept and track inbound. Approach speeds acceptable. No BAZ signal received during missed approach, and it was noted that AZ signal was being received in BAZ coverage area.

3. Approach #2 - flap 15°, props 1070 RPM, low RMP selection did not provide desired manoeuvrability, particularly tracking glideslope. When two dots high on glideslope could not recapture in adequate time.

4. Approach #3 - flap 15°, props 1200 RPM. With props up and 120 kt. approach speed, it was difficult to capture the glideslope from above. At two dots high at start of recapture, some 5000 ft. of airspace needed. A simulated engine failure of Eng. #1, and an aircraft weight of 38,000 lbs. did not present any problems during the missed approach. All climb gradients met.

5. Approach #4 - flap 15°, props 1200 RPM. Test started off two dots high on glideslope, and two dots off course of azimuth. No problem in capturing AZ, but 5000 ft. needed to capture and stabilize on glideslope. At one dot high, it was much more reasonable to capture glideslope. Management of aircraft manoeuvring was good throughout the flight profile. No problems experienced in the transition to a landing configuration. No problems experienced during the IFR departure and climb. All desired altitudes met with climb gradients outlined in approach chart.

6. Approach #5 - 45° flap, props 1200 RPM. Additional flap demonstrated no problem of capturing the AZ and EL at two dots off course, and two dots high on the glideslope. As engine torque was applied for the go-around, flap dump was experienced, but did not adversely affect the aircraft's handling characteristics. A go-around was selected from a short final, and no difficulties were experienced.

7. Approach #6 - 45° flap, props 1200 RPM, Steep approach 9.7° handled by 45° flap.

8. Flap 15° was considered marginal in the more abnormal tests, and could develop into critical aspect if a strong tail wind was experienced. Flap 45° provided excellent control, but slow approach speed, which adds to time exposure if icing conditions experienced on approach. Flaps 25° is a recommended compromise.

9. A prop setting of 1200 RPM is to be considered optimal in the approach, for best control.

10. Pemberton NDB is well sited to act as a positive MAP indication, and is in line with AZ/EL MLS site.

11. Since Pemberton MLS will be a Class 2 private navigation aid, it is suggested that ICAO 1985 format be considered. The ICAO 1985 format provides magnetic track information on the control head, instead of 0° for the ICAO 1981 format now installed.

12. Cockpit workload does not appear to be excessive, and raw flight data is adequate rather than being coupled to a Flight Director/Autopilot. Tests showed that +- 1/2 dot can easily be held on both the AZ and EL.

13. Crew coordination is good, and no special procedures are needed. Selecting the missed approach set up at 6.0 DME inbound on front AZ (navaid and heading bug) as well as the 090° intercept heading on missed approach, are good techniques and should be incorporated into training syllabus.

14. IFR departure procedure should use props 1200 RPM and maximum continuous power on engines.

15. No serious problem with instrument and control visibility, but would suggest a light dimming capability for flight operations in the winter when low light characteristics are present.

16. Interim panel annunciator is confusing, and difficult to discern what equipment is selected.

17. Final flight test will have to have MLS receiver unstrapped to conduct at 9.7° glideslope approach.

## APPENDIX C

## FLIGHT TRACK DEVIATION DATA

During the main testing period at Pemberton in July, 1987, a video camera was located at the antenna site pointing along the nominal flight path. Several consecutive Dash-7 test runs were recorded and a grid reference mask centred in the camera frame was superimposed on the final tape. The DME range as measured on the aircraft was read over the radio at intervals and recorded on the videotape along with the comments from the ground observer. Combining these range measurements with the known distance between the aircraft landing lights on the wings, the overlaid mask dimensions were estimated as a rectangle measuring 2.0 degrees by 0.8 degrees on the sides.

The attached Figures indicate the motion of the nose wheel located landing light relative to the overlay mask, as recorded on the video for eight consecutive runs made on the same day (there was no run #5 recorded). The most distant point at which the landing lights were reliably visible on the videotape was 8nm and is the start point for the tracks shown; the tracks are shown dashed when the slant range dropped below 2nm. The aircraft track in all tests was biassed to the east of the mask centre. However, the recorded commentary of the ground observer and the aircraft test crew did not indicate such a bias in the flying. The most likely cause for the bias would be a small misalignment of the camera pointing angle to the west. Overall, even if the bias is pilot/system induced, the deviation and the drift from the desired path as indicated in the video is small.

For each test, the maximum and minimum and mean angles of aircraft track deviation from the camera pointing angle were recorded for the elevation and azimuth planes (y and x directions respectively) for the period from 8nm to 2nm slant range. The mean values obtained from these data are:

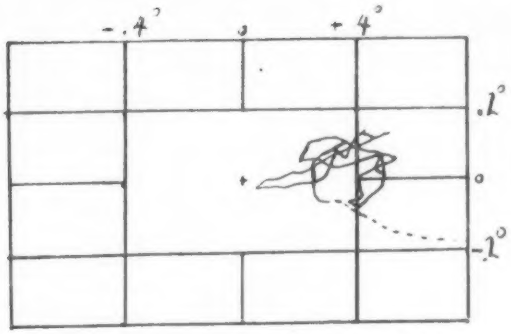
Elevation deviation = 0.05 +/- 0.1 degrees

Azimuth deviation = 0.4 +/- 0.2 degrees

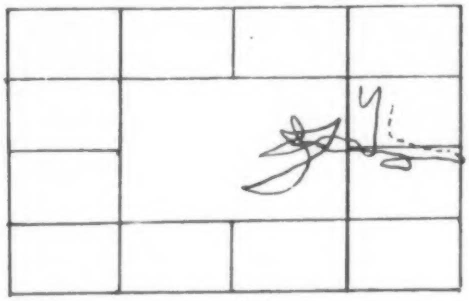
Although the tracks in the accompanying figures are difficult to interpret, the videotapes show that the angular deviation is fairly uniform over the distances from 10nm (where the aircraft captured the glide path) all the way down to about 2nm (where the aircraft begins to break away from the glide path to follow the missed approach track). These deviations represent lateral excursions of up to 500 feet at 10nm and 100ft at 2nm. Vertical deviation at 10nm is no more than 150 ft; at the 2nm range, prior to the break off, there is always less than the 50 ft the formula would predict because the vertical deviation is more closely controlled at the missed approach point.

PEMBERTON STOL/MLS TESTS: JULY, 1987

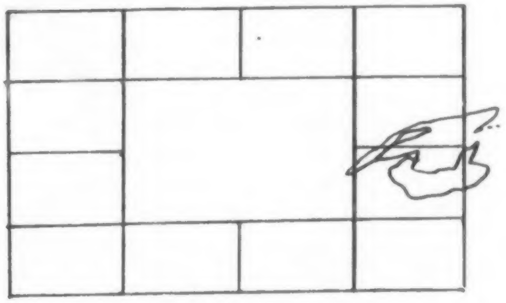
DASH-7 on a 7.7 degree approach
Tracking from 8nm to 2nm range



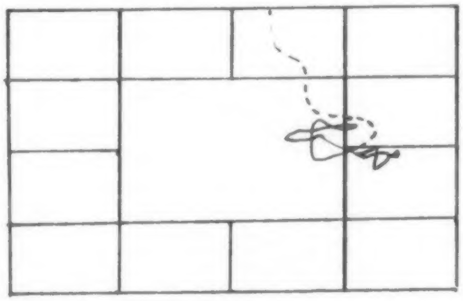
#3



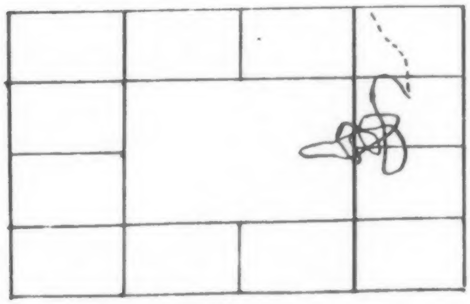
#4



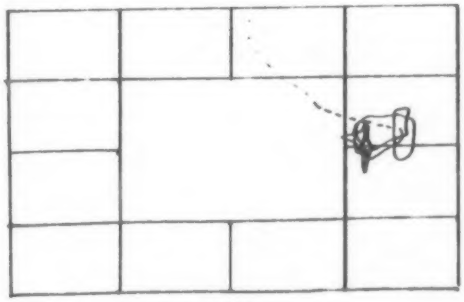
#6



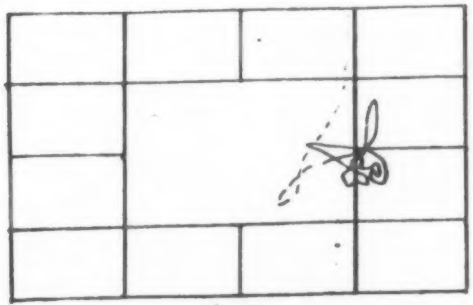
#7



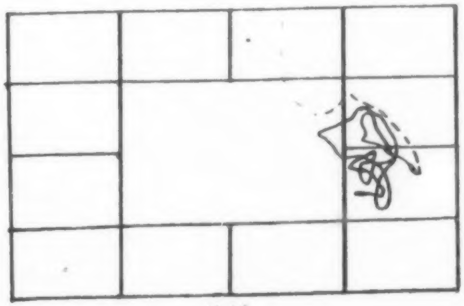
#8



#9



#10



#11